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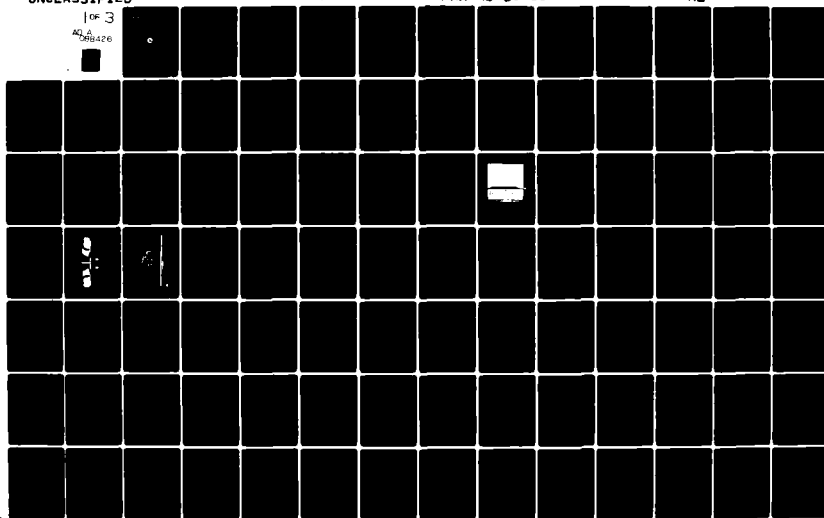
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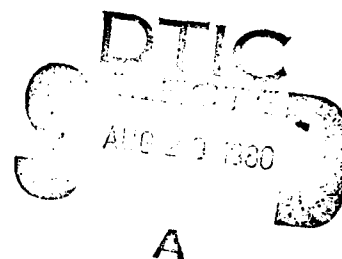


Report No. FAA-RD-80-60

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AIRBORNE RADAR APPROACH FLIGHT TEST EVALUATING VARIOUS TRACK ORIENTATION TECHNIQUES

L.D. King



June 1980

Final Report

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Prepared for

**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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16. Abstract This comprehensive report presents the results of a flight test experiment of an Airborne Radar Approach (ARA) System utilizing various track orientation techniques and operational modes. The tests were performed in the immediate area of NAFEC in Atlantic City, N.J. The test environment involved the airport terminal area and offshore sites. The test aircraft was a NASA CH53A helicopter manufactured by Sikorsky Aircraft and currently based at NAFEC. The test period was from January 1979 to February 1979 and from June 1979 to August 1979. Flight tests for ARA accuracy and procedures development were performed in six distinct operational modes. These were as follows: beacon w/cursor, multiple beacon, skin paint, skin paint w/cursor, combined and beacon-only modes. The specific program objectives can be summarized as follows: 1) to evaluate the ability of the radar operator to guide an aircraft along a predetermined path using various track orientation techniques, namely: the cursor and multiple beacon techniques; 2) to assist the FAA in developing and certifying standard ARA procedures and weather minimums; 3) to define and quantify specific ARA system functions and characteristics for use in a Minimum Operational Performance Standards (MOPS) document. The primary conclusions of this flight test experiment were: the ARA system performed satisfactorily from both an accuracy and an operational viewpoint in all six operational modes, the ARA performance utilizing the track orientation techniques showed marked decrease in the overall Total System Cross Track (TSCT) and Flight Technical Error (FTE) quantities; the cursor and multiple beacon techniques also eliminated the tendency to "home" to station; in the skin paint mode distinguishing offshore targets such as lighthouses from ships and other surface objects is virtually impossible.		13. Type of Report and Period Covered 9) Final Report
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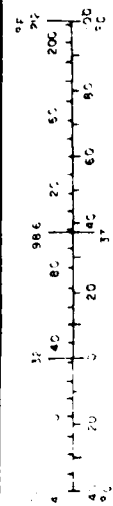
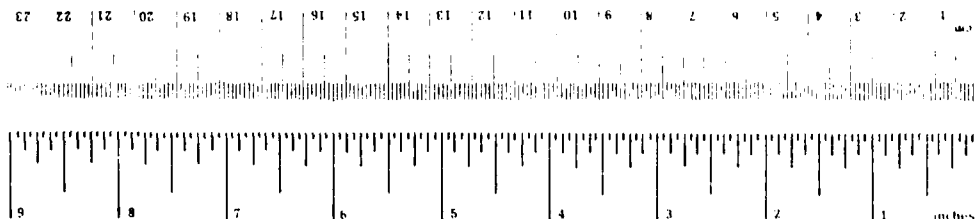
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
sq in	square inches	6.5	square centimeters	cm ²
sq ft	square feet	0.09	square meters	m ²
sq yd	square yards	0.8	square meters	m ²
sq mi	square miles	2.6	square kilometers	km ²
acres	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	2000 lb			
VOLUME				
1/2 p	teaspoons	5	milliliters	ml
1/4 p	tablespoons	15	ml	ml
1/2 p	fluid ounces	30	milliliters	ml
1 p	cups	0.24	liters	l
1 p	quarts	0.95	liters	l
1 p	gallons	3.8	liters	l
1 cu ft	cubic feet	0.03	cubic meters	m ³
1 cu yd	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
F	Fahrenheit temperature	5/9 after subtracting 32	Celsius temperature	C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
C	Celsius temperature	9/5 then add 32	Fahrenheit temperature	F



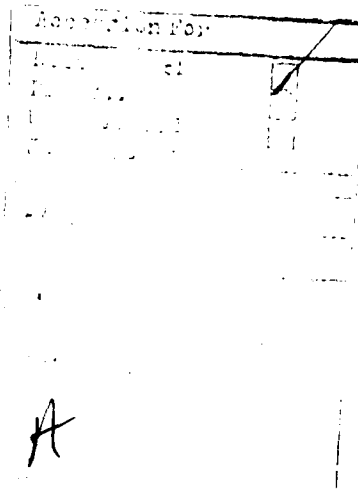


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1.0

EXECUTIVE SUMMARY

An overview of the analysis of the performance of airborne radar as an approach aid utilizing various track orientation techniques and operational modes is presented in this executive summary. In order to attain the proper perspective and to understand the impact of these results it is necessary to briefly review the experiment design, the equipment used and the test objectives. This section begins with a review of these important issues and then summarizes the overall method of approach used to answer operational, functional and accuracy questions.

1.1 BRIEF DESCRIPTION OF TESTS PERFORMED AND EQUIPMENT UTILIZED

The Airborne Radar Approach (ARA) System Flight Test Experiment was initiated by the Systems Research and Development Service of the Federal Aviation Administration (FAA). The flight tests were performed by the Approach and Landing Branch of the FAA's National Aviation Facilities Experimental Center (NAFEC). The tests were supported by Systems Control, Inc. (Vt.) in the areas of test planning, data collection/reduction and final report preparation.

The ARA tests were performed utilizing the Bendix RDR-1400A and RCA Primus-50 radar systems. The test vehicle was a CH53A helicopter manufactured by Sikorsky Aircraft and currently based at NAFEC. Four test pilots were provided by NAFEC as subjects for this experiment. The ARA test flights were performed in the general area of NAFEC. Test airspace environments included both the airport terminal area and offshore sites. Flight tests for ARA accuracy and procedures development were performed in the beacon with cursor, multiple beacon, skin paint, skin paint with cursor, combined and beacon-only modes. The testing period was from January 1979 to February 1979 and from June 1979 to August 1979.

1.2 SUMMARY OF TEST OBJECTIVES

The ARA flight test experiment was designed to obtain both quantitative and qualitative data in the areas of system accuracy, ARA procedures, ARA functional requirements and ATC operational integration problems.

Specific program objectives can be summarized as follows:

- 1) To evaluate the ability of the radar operator to guide an aircraft along a predetermined path using various track orientation techniques, namely: the cursor and multiple beacon techniques.
- 2) To assist the FAA and the user community in developing and certifying standard ARA procedures, associated weather minimums and obstacle clearance requirements.
- 3) To define and quantify specific ARA system functions and characteristics for use in a Minimum Operational Performance Standards document.

1.3 METHOD OF APPROACH

The basic ARA test program consisted of approach testing in six major test configurations. These were defined as, Beacon with Cursor Tests, Multiple Beacon Tests, Skin Paint Tests, Skin Paint with Cursor Tests, Combined Mode Tests and Beacon-only Tests. Twenty-five flights with 88 approaches were flown in the Airborne Radar approach experiment. Of these twenty-five flights, four were performed using the modified Bendix radar system in the beacon with cursor mode, ten flights were performed in the multiple beacon mode, six were accomplished in the skin paint and skin paint with cursor modes, and the remaining five flights utilized the RCA Primus-50 radar system in the combined and beacon-only modes.

The single beacon with cursor tests were conducted at the airport site utilizing the modified Bendix RDR-1400A Radar system. The modified radar system generated an additional azimuth line or cursor on the radar screen. The cursor, which represents course error, represents the intended approach course selectable on the Horizontal Situation Indicator (HSI). Two different types of approaches (direct and overhead straight) were conducted during this phase of testing so as to provide a reasonable data base in order that cursor aided approaches could be compared to non-cursor aided approaches. The multiple beacon testing concentrated on using two independent ground beacons to establish visual reference indications of the desired final approach course on the airborne radar display. The skin paint and skin paint with cursor portion of the testing utilized the Bendix radar system. The effort in this portion

of the testing was to use a prominent surface object (Brandywine Lighthouse) to simulate Airborne Radar Approaches to offshore sites with and without the aid of a cursor. The RCA Primus-50 testing was conducted at the offshore site in the combined and beacon-only modes. The purpose of these tests was to determine the operational viability of the combined beacon/ground mapping mode in a offshore environment. Quantitative data was obtained for all of the above mentioned test areas.

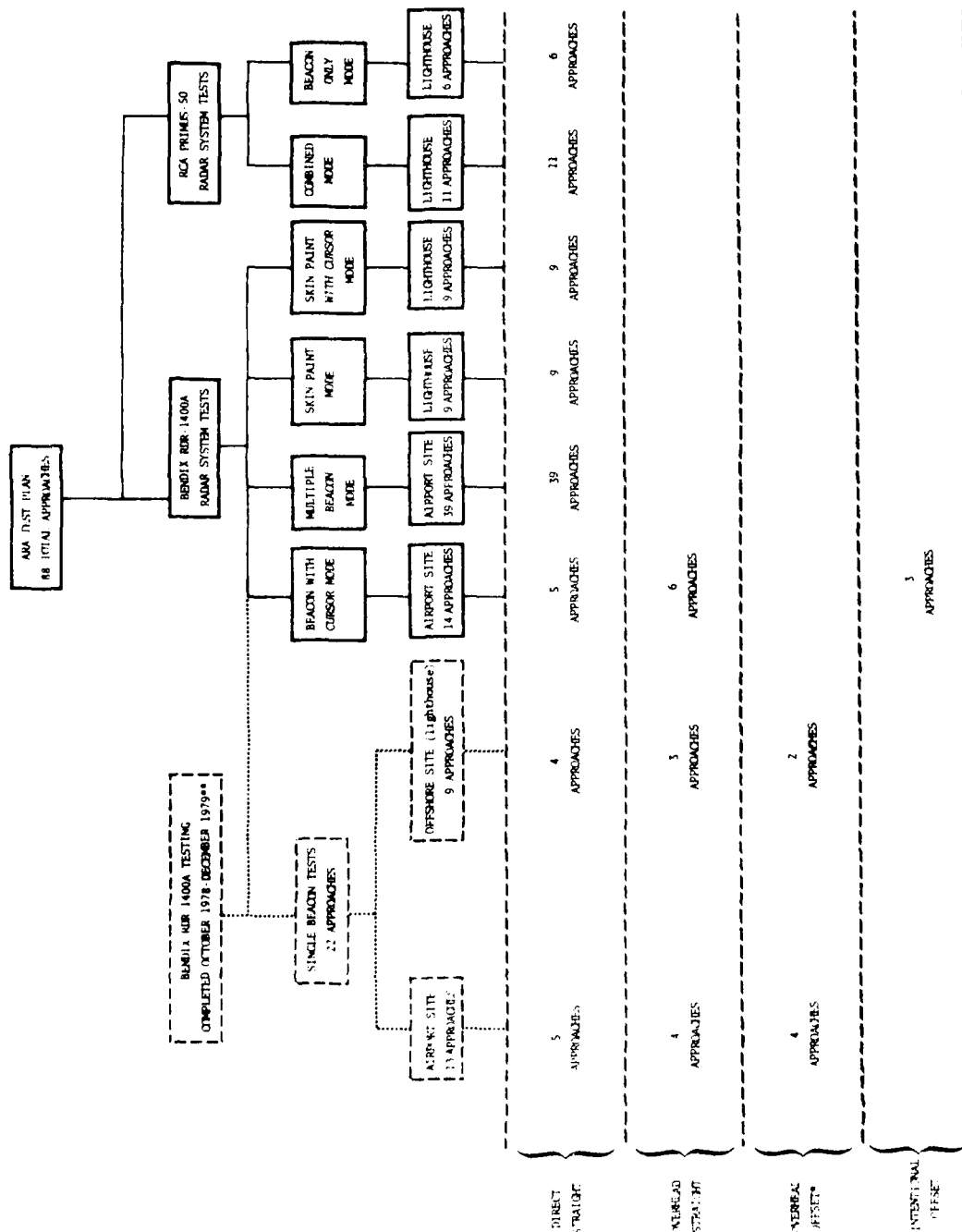
Four subject pilots* were used for the Airborne Radar Approach flight test program. All four pilots alternated as pilot and copilot during the test program. The subject pilots had previous experience flying ARA approaches. This experience was obtained from the single beacon approach testing conducted at NAFEC during the test period from October 1978 to December 1978 (Reference 1). In any case the proficiency in using the airborne radar came about through actual operational use.

There were two pilots per crew, with the copilot being the only crew member hooded. For safety reasons, the pilot was not hooded, but was instructed to fly only those course headings indicated by the copilot. It was also the pilot's responsibility to handle all communications.

Two separate testing sites were used for the ARA experiment. These were: airport testing conducted in the NAFEC terminal area and offshore testing conducted in Delaware Bay using Brandywine Lighthouse. In addition, two different types of approaches were conducted at the airport site (direct straight and overhead straight) while only one approach type (direct straight) was utilized at the offshore site. Pilot procedures and profiles were generated in advance in order to insure a well disciplined test environment.

Figure 1.1 summarizes the overall ARA flight test program. This figure shows that a total of eighty-eight approaches were flown: 14 in

/NOTE/ *Due to the retirement of one subject pilot after the multiple beacon testing the three remaining pilots completed the flight test program.



/NOTE/ *ONLY THE INITIAL SEGMENTS OF THE OVERHEAD OFFSET APPROACHES WERE UTILIZED FOR COMPARATIVE PURPOSES

**THE RESULTS OBTAINED FROM THIS TEST PERIOD WERE USED FOR COMPARISON PURPOSES ONLY (THE RESULTS WERE PRESENTED IN FAA REPORT NUMBER FAA-RD-79-99)

Figure 1.1 Overall ARA Flight Test Program Summary

the beacon with cursor mode, 39 in the multiple beacon mode*, 9 in the skin paint mode, 9 in the skin paint with cursor mode, 11 in the combined mode and 6 in the beacon-only mode. The dashed portion of Figure 1.1 provides the breakdown of flight testing conducted in the single beacon mode (Reference 1). These data were included in this report so that comparisons could be made with the cursor aided, multiple beacon and skin paint approaches. Figure 1.1 provides the detailed breakdown of the number and type of approaches flown in each specific mode of operation. In addition, Figure 1.1 shows the experiment balance between interexperiment variables for each mode (e.g. the balance between skin paint and skin paint with cursor approaches). The final point of interest presented in the figure is the number and type of each approach flown in the airport terminal and offshore areas. As shown in the figure, three approach procedures (direct straight, overhead straight and overhead offset) were utilized during the previous single beacon testing, while only two approach procedures (direct straight and overhead straight) were utilized during the track orientation technique testing. In addition, a fourth procedure (intentional offset) was utilized at the airport site in the beacon with cursor mode. The intentional offset procedure was used to intentionally misplace the aircraft off course at a position the aircraft had acquired in previous single beacon testing. This procedure was utilized to determine the ability of the radar operator to acquire and track the intended course using the cursor technique.

The direct straight was used when the winds were favorable for landing upwind in the approach direction and obstruction clearances permitted descent to minimums. The overhead straight was used when the winds favored an opposite direction when approaching the landing site. The procedures used for flying both profiles were identical, with one exception. On the overhead approaches it was necessary for the copilot to call out when directly overhead the target so that the pilot could start an outbound timing of 25 minutes. At the end of 25 minutes a

/NOTE/ *Twenty-four approaches were non-recoverable from the film interpretation standpoint because the beacon return was splayed across the entire azimuth of the screen. This splaying occurred because the Bendix Radar's STC circuit was misadjusted.

procedure turn was executed and the Intermediate Approach Course was acquired. The accuracy with which each of these approach procedures was executed was determined in detail. These results are presented and discussed in-depth in Section 5.3 for each of the test areas: airport and offshore. The discussion in Section 5.3 also presents an in-depth look at the various operational modes and track orientation techniques tested.

A more detailed description of specific flight profiles, the equipment used, the test procedures, the subject pilots and the data collection/reduction/analysis procedures is presented in Sections 4.1, 4.2, 4.3, 4.4 and 4.5.

1.4 RESULTS AND CONCLUSIONS

This section presents a generalized summary or overview of the primary results and conclusions which may be found in Sections 5.0, 6.0 and 7.0. A detailed analysis and expanded discussion of each of the major test areas and operational modes indicated in Figure 1.1 is contained in Section 5.0. A comprehensive discussion of pilot/copilot procedural operations using ARA is contained in Section 5.2. Section 6.0 is structured to present the data applicable to specific MOPS questions raised by the Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC-133) on ARA. Finally, Section 7.0 presents a more detailed and expanded discussion of the qualitative conclusions regarding ARA as a non-precision approach technique utilizing various track orientation techniques and operational modes. The following subsection will provide a summary of results and conclusions obtained during the flight test program.

- 1) The modified Bendix RDR-1400A Airborne Radar Approach System tested performed satisfactorily from both an accuracy and an operational viewpoint in the single beacon, with cursor mode.
 - The error quantity used to measure this performance was Total System Cross Track (TSCT) error. A comparison of summary data between the single beacon and single beacon with cursor approaches over the length of the approach courses for the airport environment is as follows:

TSCT	Operational mode
$\pm 1\sigma$	

1.36 nm	Single Beacon
.57 nm	Single Beacon W/Cursor

- The results indicated a large reduction in the TSCT and FTE values for the cursor-aided approaches. The FTE values determined during flight test at the airport site were as follows.

FTE	Operational Mode
$\pm 1\sigma$	

1.44 nm	Single Beacon
.76 nm	Single Beacon W/Cursor

- The ARA lateral track keeping accuracy (TSCT) was well within specified obstacle clearance airspace limits, ± 4 nm established by the RTCA SC-133 MOPS.
 - The cross track Airborne System Error (ASE) and the Along Track Error (ATE) for the Bendix radar system were consistently small and showed no dependency on distance from the target.
- 2) ARA performance in the multiple beacon mode showed basically the same results obtained in the beacon with cursor mode. That is, the track orientation afforded by the multiple beacon mode reduced the overall TSCT and FTE values for the approaches flown at the airport site. These values were as follows:

TSCT	FTE	Operational Mode
$\pm 1\sigma$	$\pm 1\sigma$	

1.36 nm	1.44 nm	Single Beacon
.60 nm	.70 nm	Multiple Beacon

- 3) ARA performance was quantified in both the skin paint mode and the skin paint with cursor mode approach testing conducted at the offshore site. The results indicated three distinct items.
- If the target is positively identified, ARA approaches in the skin paint mode can be executed as accurately as single beacon approaches. The following TSCT and FTE results support this fact.

TSCT	FTE	Operational Mode
+1 σ	+1 σ	
.89 nm	1.02 nm	Single Beacon
.34 nm	.64 nm	Skin Paint

- Offshore targets such as ships provide bright returns but are not distinguishable from the intended target (an oil rig).
- The cursor-aided approaches flown in the skin paint mode indicate an improvement in the FTE quantities. These FTE quantities are improved because of the track guidance offered by the cursor. The TSCT and FTE values were as follows:

TSCT	FTE	Operational Mode
+1 σ	+1 σ	
.34 nm	.64 nm	Skin Paint
.57 nm	.48 nm	Skin Paint W/Cursor

- 4) Technically and operationally the RCA Primus-50 performed well in the combined and beacon-only modes. System performance results (ASE and ATE) indicate that the system provided accurate guidance to the target. The TSCT and FTE values calculated were as follows:

TSCT	FTE	Operational Mode
+1 σ	+1 σ	
.40 nm	.64 nm	Combined
.42 nm	.69 nm	Beacon-only

- Operationally the combined mode offers one serious problem. Because of the large beacon return displayed, surface objects in the immediate area surrounding the intended target are blocked out, therefore offering limited obstacle clearance information.
- 5) ARA System functions and characteristics were investigated to satisfy the requirements of RTCA's SC-133. These were in the areas of technical performance and operational performance. A brief summary of the details discussed in Section 6.0 is provided in the following list.

TECHNICAL PERFORMANCE

A. RANGE PERFORMANCE

- (1) Single Beacon - 21 nm at 1000 feet altitude with the beacon at ground level.
 - 35 nm at 1000 feet altitude with the beacon at 30 feet above water level.
- (2) Skin Paint - 20 nm at 1000 feet with relatively low background clutter. (Brandywine lighthouse was utilized as the target.)

B. BEARING ACCURACY

- (1) Bendix RDR-1400A - At 5 nm from the target one-sigma numbers range in value from $\pm 3.1^\circ$ to $\pm 5.4^\circ$. At 10 nm the one-sigma values were determined to be $\pm 2.2^\circ$ to $\pm 3.8^\circ$.
- (2) RCA Primus-50 - At 5 nm and 10 nm from the target the one-sigma values were determined to be $\pm 2.0^\circ$ and $\pm 3.5^\circ$ respectively.

C. DISPLAY READABILITY - Not a specific test variable. Qualitative observations indicated that the readability was adequate except in direct sunlight.

D. DISPLAY RESOLUTION - Not a specific test variable. Observations and calculations showed the radar displays tested had adequate resolution. In addition, the displayed size of the beacon return did not adversely affect the pilot's ability to conduct the approach.

OPERATIONAL PERFORMANCE

- A. BEACON/GROUND CLUTTER DISCRIMINATION - The combined beacon/ground mapping mode was found to be operationally feasible, but because of the large displayed beacon return obstacles within the immediate area of the intended target were blocked out.
- B. OFFSHORE TARGET DISCRIMINATION - It was discovered during the offshore skin paint testing that while executing approaches to the lighthouse it was often times difficult to distinguish between ships and the lighthouse.
- C. CURSOR INTERPRETATION - The use of an electronically generated course direction cursor, which obtains its inputs directly from HSI course selection proved very effective. Results indicate a marked reduction in the TSCT and FTE quantities.
- D. PERFORMANCE IN THE SKIN PAINT AND SKIN PAINT W/CURSOR MODES - The only serious problem encountered was that of positive target identification.
- E. PERFORMANCE IN THE SINGLE BEACON W/CURSOR MODE - Results indicate that the tendency to home to the station is eliminated with the cursor technique. Also, the cursor decreases the level of mental workload required to fly the approach.
- F. PERFORMANCE IN THE MULTIPLE BEACON MODE - Results indicate that by utilizing two longitudinally separated beacons track guidance is improved. It was also discovered that the level of mental workload is increased because the track angle error is not directly displayed on the radar.
- G. RCA PRIMUS-50 COMBINED AND BEACON-ONLY MODE PERFORMANCE - Operationally the RCA Primus-50 performed well in both modes of operation. The only major problem encountered was the large displayed beacon return (See A).

2.0

INTRODUCTION

This report was prepared to summarize the results of the Airborne Radar Approach (ARA) flight tests. These tests were performed by Approach and Landing Branch (ANA 110) of the Federal Aviation Administration's National Aviation Facilities Experimental Center (NAFEC). The tests were supported by Systems Control, Inc. (Vt.) [SCI (Vt.)] in the areas of test planning, data collection/reduction and final report preparation. The test vehicle was a CH53A helicopter manufactured by Sikorsky Aircraft. Flight tests for ARA accuracy and procedures development were performed in two distinct operational environments. These were the airport environment and the offshore environment. The airport ARA tests were performed at NAFEC and the offshore tests were conducted nearby in Delaware Bay. The testing period was from January 1979 to February 1979 and from June 1979 to August 1979. The primary reasons for the ARA flight test program were: 1) to evaluate the ARA concept both quantitatively and qualitatively in the areas of accuracy and flight procedures involving various track orientation techniques and modes of operation; 2) to provide empirical inputs for the "Minimum Operational Performance Standard" being generated by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 133 (SC-133).

2.1 BACKGROUND

Continued expansion in the application of helicopters to the accomplishment of civilian oriented tasks depends to a significant extent on the capabilities of the aircraft and the navigation systems in order to operate in all weather conditions. Much of the future growth of the helicopter market will be in applications that involve the transport of people in such areas as offshore oil support, in corporate transport, and eventually in scheduled transportation. The effectiveness of the helicopter in these missions depends on its ability to circumvent the time delays of other modes of transportation. If weather results in a significant number of cancellations and delays, the helicopter's effectiveness is lost. A particularly interesting facet of this general problem area arises from the needs of helicopter operators to fly in adverse weather in remote areas. This type of mission generates a

requirement for a self-contained helicopter instrument approach system for landing on oil rigs and other landing areas remote from conventional navigational aids. Such a system would also benefit the corporate operator who desires instrument approach minimums equivalent to conventional non-precision approach procedures at a variety of sites, many of which may be of an ad hoc nature, but who would be unable to afford the time and expense necessary to achieve the installation of ground navigation aids.

Weather radar used in the mapping mode for IFR approaches offers a possible immediate low-cost solution. The application of airborne weather/mapping radar as an approach and landing aid has generally become known throughout the industry as an Airborne Radar Approach (ARA) System. This terminology will be used frequently in this document.

The major impetus for the ARA operational application has come from the Helicopter Association of America (HAA) in general, and its offshore energy exploration support members in particular. In addition to the basic requirements of the HAA to stimulate the development of helicopter IFR procedures and systems, particularly at sites where instrument approach procedures are unavailable, the necessity to provide approach capability to offshore oil rigs under Instrument Meteorological Conditions (IMC) is critical to their mission. The HAA, therefore, has consistently requested the FAA to develop standard operational procedures and equipment certification criteria as regards ARA systems and their operation in the IFR portion of the National Airspace System as one means of providing instrument approach and landing capability. Certain offshore helicopter operators have been granted approval for ARA approaches on a singular basis, but no general certification criteria currently exists within the FAA.

In recognition of the emerging need for some measure of equipment performance criteria, early in 1977 the Radio Technical Commission for Aeronautics (RTCA) constituted a Special Committee (SC-133) for the purpose of developing a Minimum Operational Performance Standards (MOPS) for ARA systems for helicopters. This MOPS document will contain both operational and technical performance criteria which might ultimately be

used for FAA certification purposes. At least two requests have been made of the FAA by RTCA, in behalf of SC-133, which contains a postulated operational scenario and initial technical performance specifications. However, no substantive technical data was previously available on many of the critical issues concerning the ARA system application.

2.2 ARA TEST CONCEPTS

Many test programs are limited by the practical considerations of time and money. In the case of the ARA testing these were additional considerations which further limited the investigation. It is therefore necessary to identify in some detail what this ARA evaluation does and does not cover.

Most of the following discussion concerning the ARA flight test limitation emanate from considerations of the aircraft used as the test vehicle. The Sikorsky CH53A has sufficient passenger and payload capacity for experimental test purposes, however, due to limited fuel capacity, it has an effective flight endurance of approximately 1-3/4 hours. For this reason it was decided to limit the offshore portion of this evaluation to the Brandywine Lighthouse located in Delaware Bay. Brandywine Lighthouse was located within the useable operating radius of the aircraft while the existing oil rigs are located 60 miles east of Atlantic City. Section 4.0 identifies the specifics of the test design. Approximately 20 hours of the 30 hour flight test program were assigned to offshore testing. The remainder of the testing was dedicated to the airport beacon with cursor testing.

In order to investigate a spectrum of target signatures and various track orientation techniques it was decided to investigate radar performance against: a) skin paint targets over water, b) skin paint targets utilizing the cursor technique, c) beacon and skin paint targets over water (combined mode), d) beacon targets over water, e) beacon targets over land utilizing the cursor technique, and f) multiple beacon targets over land.

Two other issues relating to the scope of the current effort should be discussed. First, there were two airborne radar systems available for test, the RCA Primus-50 and the Bendix RDR-1400A. Both systems have both primary ground mapping and beacon modes. In addition, the PCA unit has a combined beacon/ground mapping mode (which was included as a requirement in the ARA MOPS generated by RTCA SC-133). Since the combined beacon/ground mapping mode was a requirement in the ARA MOPS, six of the thirty hours of the flight test program were dedicated to the RCA Primus-50 combined mode testing. Also the Primus-50 was tested in the beacon-only mode. The skin paint and cursor testing utilized the Bendix RDR-1400A radar system. For the cursor testing the Bendix radar system was modified to electronically display a cursor which indicates track angle error utilizing synchro inputs from the Horizontal Situation Indicator (HSI).

The second issue relates to the subject of the pilot population sample used for these tests. Radar display interpretation and pilot steering techniques form a major portion of this investigation. Although a wide variety of subject pilots is usually a goal in the design of such flight experiments, due to the small number of flight hours available for these tests, the number of pilots used was limited to three. During the single and multiple beacon testing a fourth pilot was utilized but because of his retirement only three qualified C-53A pilots remained. The subject of pilot performance variability should properly be studied in a more comprehensive and dedicated experiment.

2.3 PURPOSE OF THE TESTS

Simply stated, the purpose of this ARA test program was twofold. First, to acquire a statistically significant data base, concerning operational procedures utilizing various track orientation techniques and overall ARA system performance that will assist the FAA and the airspace users alike in developing and certifying standard approach procedures and associated weather minimums through the application or modification of TERPS criteria. Second, to quantify specific ARA system performance parameters for use by RTCA SC-133 and the FAA in specifying ARA required technical performance. Each of these major objectives is expanded and discussed in depth in the following sections.

2.4 ORGANIZATION OF THE REPORT

The results of the ARA flight test program are presented in the remainder of this report. Section 4.0 provides a detailed equipment summary, a flight test description, a review of test profile designs, data acquisition procedures and data reduction/analysis techniques. Sections 5.0 presents and documents the specific results obtained in five major areas:

- 1) Airborne Radar as an Approach Aid
- 2) Analysis of Pilot Procedures
- 3) Detailed Accuracy Data
- 4) Operational Evaluation of the ARA Concept

Section 6.0 presents a summary of the technical and operational performance of the ARA System. Finally, Section 7.0 presents major qualitative conclusions as they relate to the stated program objectives from Section 3.0

3.0

DETAILED TECHNICAL OBJECTIVES

The general objectives of the ARA track orientation concepts were to evaluate and/or establish basic ARA operating procedures and overall system performance so that a direct quantitative comparison could be established between the raw radar return testing and the cursor aided or multiple beacon testing. The results of this program are therefore applicable to the FAA, RTCA and the user community (HAA). For purposes of discussion these test objectives have been grouped into two categories, namely Technical and Operational. Subsequent to this discussion, a correlation will be presented between the stated test objectives and the specific test results obtained (Section 5.0).

A. Technical Performance Objectives

- 1) Range Performance -- To establish the maximum and minimum radar ranges at which beacon and skin paint targets, respectively, can be acquired, identified and tracked. SC-133 has specified a minimum range requirement of at least 25 nm in clear weather and 15 nm with 4 mm/hr/nm of intervening precipitation. Minimum range is specified at 1000 ft.
- 2) Bearing Accuracy -- To determine, for the system tested, the accuracy in bearing with which a target can be displayed; SC-133 requires $\pm 3^\circ$.
- 3) Display Readability -- To validate the specified display readability. SC-133 currently requires that the display be functionally readable when viewed under conditions of 20,000 lux impinging upon the display face.

- 4) Impact of Antenna Stabilization -- To validate the requirement of SC-133 for antenna stabilization up to a vector sum of $\pm 30^\circ$ for combined roll, pitch and yaw and to evaluate the impact of values in excess of $\pm 30^\circ$ on display discrimination.
- 5) Display Resolution -- To assess display resolution requirements. Although this parameter is an inherent system design characteristic, it is considered desirable to obtain data on subjectively viewed display resolution for comparison with the requirements of SC-133.

B. Operational Performance Objectives

- 1) Beacon/Ground Clutter Discrimination -- To evaluate the operational viability of the combined beacon/ground mapping mode of operation as currently required by SC-133.
- 2) Offshore Target Discrimination -- To evaluate the ability of the ARA system to acquire and identify offshore targets in a variety of back scatter conditions as influenced by sea state and water depth parameters. While not an explicit test variable, careful note should be made of such conditions during each test in order to establish any possible correlation.
- 3) Cursor Interpretation -- To evaluate the ability of the radar operator to guide an aircraft along a predetermined path using an electronically generated cursor which obtains its input directly from HSI course selection. This modification should provide the operator with orientation guidance relating to aircraft position and heading, desired course, and target location.

- 4) Beacon Proximity -- To evaluate the effect of range between multiple beacons such that individual targets can be acquired and identified.
- 5) Lateral Cross Track Error and Flight Technical Error -- To establish statistically significant values for lateral cross track error for the overall ARA system and lateral flight technical error for the pilot/operator under actual operational approach conditions for each of the basic modes of operation (beacon, beacon w/cursor, multiple beacon, skin paint, combined and skin paint w/cursor). These values quantify the ability of the pilot to utilize the ARA system to maintain a desired lateral ground track.
- 6) Longitudinal Along Track Error and Letdown Error -- To establish statistically significant values of longitudinal along track error for the overall ARA system and the along track flight technical error (Letdown Error) for the pilot/operator. These values quantify the ability of the pilot to utilize the ARA system to define and identify a step-down fix and/or a missed approach point in order to execute a non-precision approach vertical profile.
- 7) Pilot/Operator Procedures, Workload and Blunder Performance -- To establish quantitative measures, whenever possible, of pilot performance factors such as operational procedures, comparative workload and blunders as related to the different ARA operating modes (beacon-only, beacon w/cursor, multiple beacon, skin paint, skin paint w/cursor and combined).

Section 4.0 which follows, describes the ARA test plan which was configured to meet these stated objectives. Following Section 4.0, a correlation between test objectives and specific flight test results is presented.

4.0

DESCRIPTION OF THE ARA EXPERIMENT DESIGN

This section describes the equipment, test profiles, procedures, subject pilots and data requirements necessary for the Airborne Radar Approach flight test program. The experiment was designed to test two different types of airborne weather/ground mapping radars as an approach aid to landing using six different modes. These are as follows: beacon, beacon with cursor, multiple beacon, skin paint, skin paint with cursor, and combined. Two distinct environments were included in the testing to determine the capability of the airborne radar to aid the pilot in making a safe approach where other navigational aids are not available. These were as follows: airport and offshore site. At the airport site two different approach profiles were utilized, while at the offshore site only one approach profile was used.

4.1 EQUIPMENT SUMMARY

This section describes the equipment used in the Airborne Radar Approach flight test program at NAFEC in Atlantic City, New Jersey.

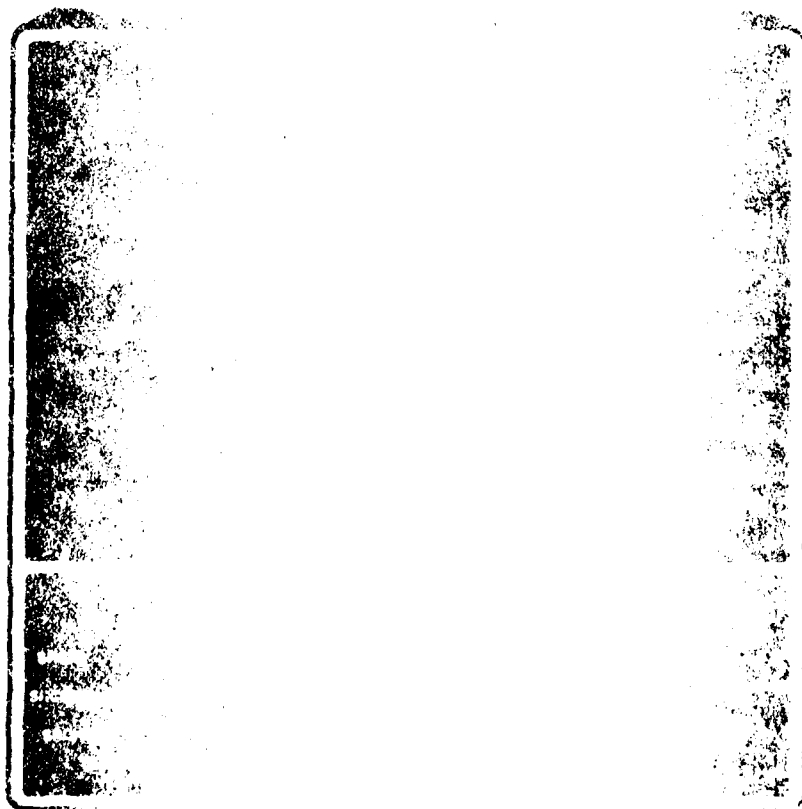
4.1.1 The Bendix RDR-1400A Radar

The Bendix RDR-1400A Radar system tested was a multi-mode, 10 KW X-band airborne radar modified to electronically produce a radar cursor display of track angle error. The system provides up to three air-to-surface search and detection modes plus the usual weather avoidance mode. It also contains the additional capability of a transponder beacon mode. The search modes provide both a ground mapping function along with the ability to detect and display prominent surface objects. The beacon mode is a special function used to interrogate and receive pulses from a ground based transponder(s) within line-of-sight range. The bearing and distance of the beacon target is then displayed on the CRT (cathode ray tube) free of any ground clutter.

The RDR-1400A uses digital techniques to continuously display a reliable return from significant weather or terrain. The display features an alphanumeric read-out directly on the screen depicting the selected mode, range, and range intervals. System checkout, either in the air or on the ground, is a straightforward procedure.

The entire
receiver-transmitter
used was a direct
mounted in a
indicator was
panel. This
accessibility
operator controls
panel as shown

units:
antenna
cable
the display
instrument
easy
controls. All
front



The mode selector switch located on the display unit offers six distinct display capabilities.

- a) SRCH 1 - Mode normally used for over water search. This mode optimizes point targets within a sea clutter background. It is generally used for mapping ground targets or surface craft at short range. This mode optimizes short range resolution and clutter rejection.
- b) SRCH 2 - Principal use for this mode is high resolution at all ranges. SRCH 2 offers no clutter rejection so it is generally use for ground mapping only. This mode offers precision ground mapping over many types of terrain.
- c) SRCH 3 - Mode normally used for the mapping of oil slicks. SRCH 3 offers long range mapping and/or maximum clutter returns.
- d) WX - Weather mode: in this mode the receiver is optimized for weather detection. It provides early warning of bad weather and possible storm activity enroute.
- e) WXA - This mode is the same as WX with one exception. When operating in the WXA mode the display flashes contoured areas to alert the pilot to clouds with high rainfall rates.
- f) BCN - This mode has the capability to interrogate beacon transponders which receive a frequency of 9375 MHz and transmit back at 9310 MHz. The BCN mode allows the pilot to navigate to a predetermined target or landing site, while continuously displaying both range and bearing to the target. This mode

eliminates any background clutter and displays only the beacon or beacons within the field of view. Depending on aircraft position and altitude, the beacon target(s) can be received at considerable distances.

The RDR-1400A also offers an indicator test pattern. When the mode selector switch is in the TEST position the pilot then has the ability to determine if the radar is operating, either in the air or on the ground. The range selector switch offers range selection from 240 nautical miles to as close as 2.5 nautical miles, full scale, with range marks varying according to different scales selected. The tilt control adjusts the tilt of the antenna in relation to the longitudinal axis of the aircraft to allow best indicator presentation. Range of tilt control adjustment is ± 15 degrees. The receiver gain is adjustable for the search and beacon modes only.

In the weather mode the gain is preset, therefore the gain control has no effect. The Scan/Stop selector switch offers the opportunity to select one of two antenna scan angles. The 120° STAB position places the antenna in a 120° scan mode, $\pm 60^\circ$ each side of the aircraft longitudinal axis. The 40° STAB position places the antenna in a 40° scan mode, $\pm 20^\circ$ each side of the aircraft longitudinal axis.

The modified radar system generated an additional azimuth line or cursor shown in Figure 4.2 as a dashed line. The angular difference displayed between the cursor and the center of the return is equal to track angle error. The cursor angle is selected on the Horizontal Situation Indicator (HSI) and the corresponding course error signal from the HSI is fed into the radar system and used as the cursor. The cursor therefore represents the track angle error and is relative to the aircraft heading which is represented by the azimuth line on the radar screen. When the cursor is aligned with the intended target the aircraft is on the desired course. As the aircraft is maneuvered onto the desired course, the track angle error signal fed to the cursor does not split the return into two parts as before.

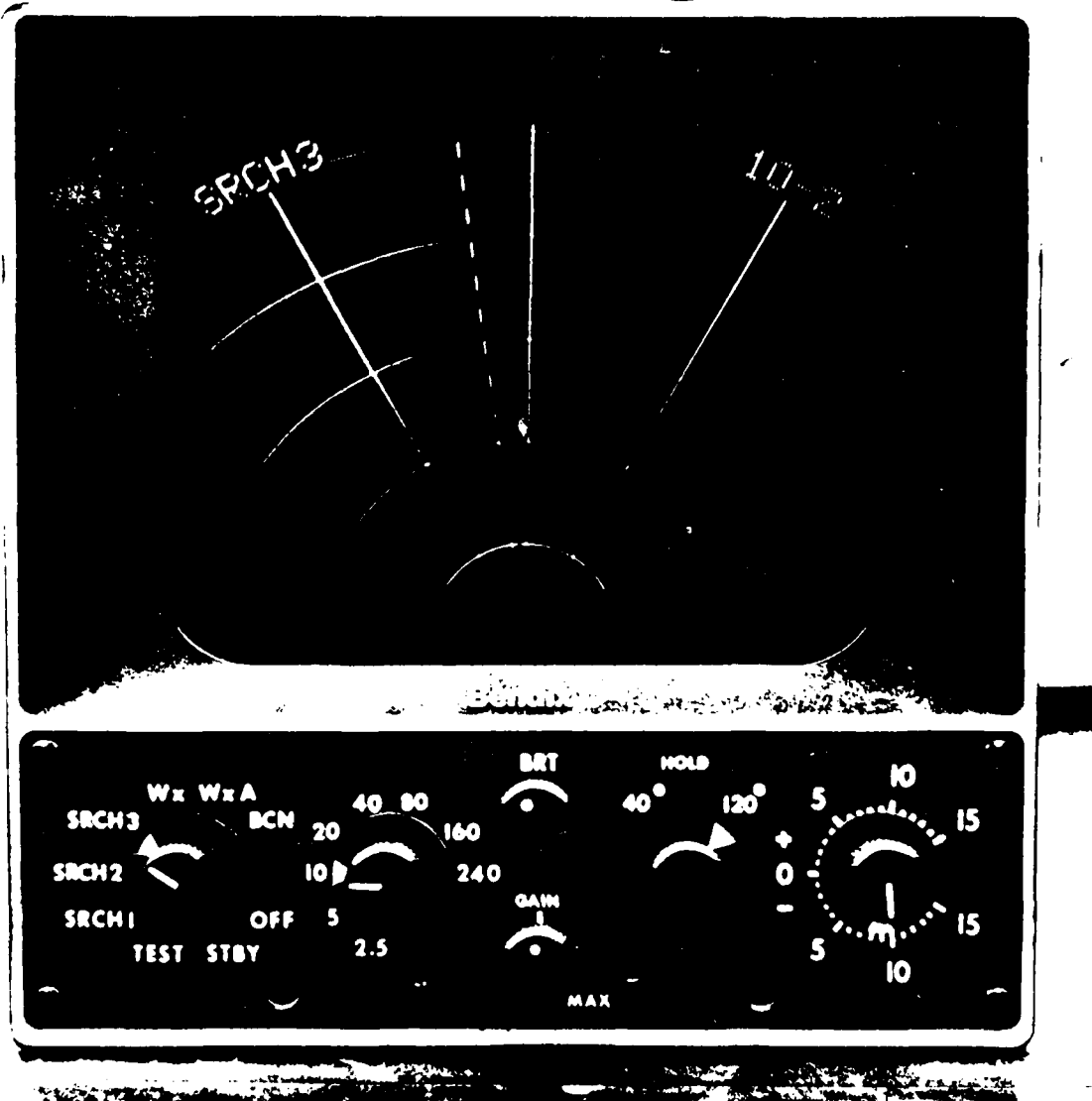


Figure 4.2 Bendix RDR-1400A Front Panel With Cursor Display

The following Figures (4.3 & 4.4) shows typical on-course and off-course indications.

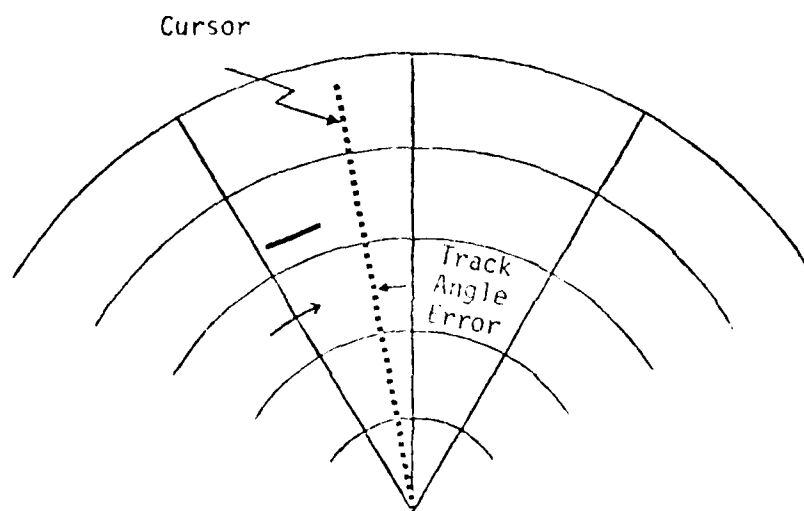


Figure 4.3 Heading Cursor Technique (Off-Course)

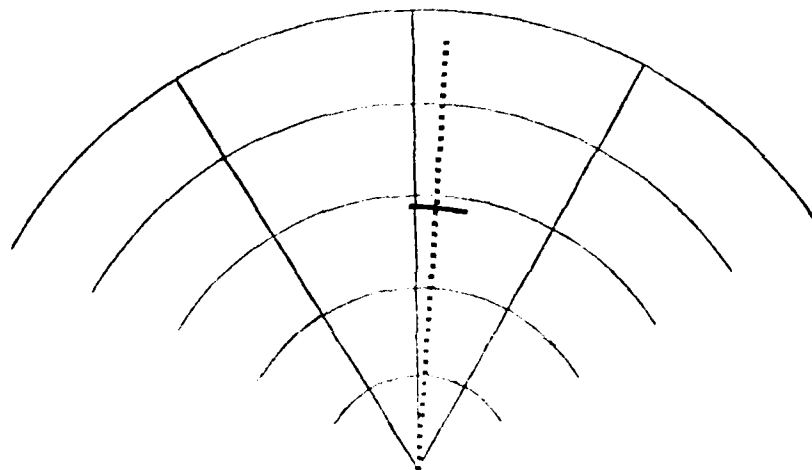


Figure 4.4 Heading Cursor Technique (On-Course)

Two rules of thumb can be emphasized when using this technique. Both apply to a no-wind situation, but with application of proper drift angle logic, will apply to any situation:

- 1) The target return should be kept between the error cursor and the 0° azimuth mark. This will insure interception of the desired final approach course prior to the missed approach point. The greater the angular distance between the return and the 0° azimuth mark the sooner the approach course will be intercepted.
- 2) Turning the direction corresponding to the direction from the error cursor to the target return will insure the proper direction of turn for course correction.

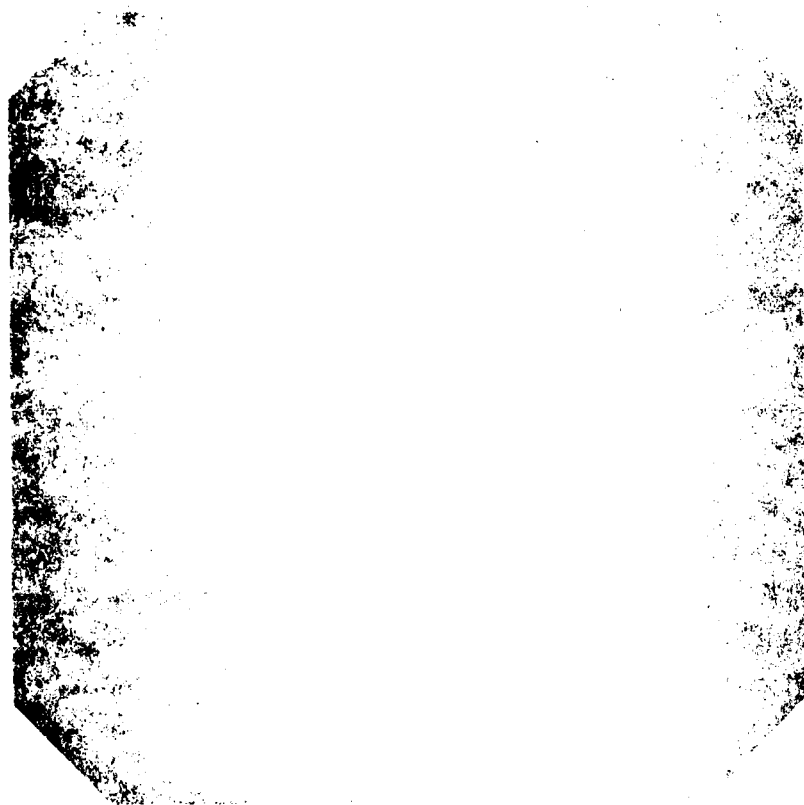
4.1.2 The RCA Primus-50 Radar

The RCA Primus-50 Radar system tested was a multi-mode, X-Band airborne radar. The system provided three distinct modes of operation. They are as follows: beacon-only, weather avoidance, and combined mode. The beacon-only mode offers the capability of being able to interrogate, within line-of-sight range, a ground based transponder(s) beacon, as in the Bendix RDR-1400A. The combined or both mode is a special function used to interrogate and receive pulses from a ground based transponder(s) while at the same time displaying surrounding ground mapped returns. The bearing and distance of the target is then displayed on the CRT along with other surrounding skin paint targets.

The RCA Primus-50 uses digital techniques to continuously display a reliable return from significant weather or terrain. The radar display itself offers no alphanumeric read-out, therefore it is necessary to read selector switches to determine selected mode, range, and range intervals.

As in the Bendix RDR-1400A the entire RCA Primus-50 system consists of 3 separate units: receiver-transmitter, display indicator, and antenna. The antenna used was a gyro stabilized twelve inch slotted flat plate antenna mounted in a radome directly on the nose of the aircraft. The display indicator was mounted in the same location as

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Bendix RDR-1400A the BCN mode allows the pilot to fly to a predetermined target or landing site, while continuously displaying both range and bearing to the target, free of any background clutter.

- b) RAD - Weather Mode: This mode offers an optimized means for weather detection. It provides early warning of bad weather and possible storm activity enroute.
- c) BOTH - Combined Mode: This mode offers the capability of receiving and displaying both primary targets and the transponder beacon return at the same time. To make the beacon return distinguishable from the primary returns the system flashes the beacon display block on and off at one second intervals.

2) Pushbutton Switches

- a) OFF - Pushbutton switch used to turn system off.
- b) STBY - Pushbutton switch used to turn radar on. Standby is useful for keeping the radar in the ready state while taxiing, loading, etc.
- c) NORM - Normal Switch used to activate the beacon and combined mode function or for routine weather mapping in the RAD mode.
- d) CTR - Contour switch enhances contours of high rainfall rate in the weather mode.
- e) CYC - Pushbutton switch used to select CYC dual operation which cause displayed contourable targets to flash on and off at 0.5 - second intervals.
- f) AZIMUTH - Azimuth pushbutton: places azimuth lines every 15°.
- g) MAP - Pushbutton switch that enables ground-mapping. This function enhances background clutter.

3) Rotary Controls

- a) RNG - Rotary range selector switch. This switch offers the operator range selection from as far out as 150 nautical miles to as close as 2 nautical miles, full scale, with range marks varying according to different scales selected. Included in this switch is the TEST mode which offers straightforward system checkout.
- b) TILT - This control enables the pilot to select desired angle of beam tilt with relation to the earth's plane. Control index references increments of tilt in degrees from 0 to 15 degrees up and down. The tilt is additive to any elevation correction by the stabilization circuits.
- c) GAIN - This rotary switch is used to adjust the sensitivity of the receiver. It offers a PRESET position used normally for weather alert and adjustable gain levels used in the beacon-only and combined modes. This switch acts as a dual function switch allowing the operator to adjust the desired CRT intensity.
- d) STAB/SWEEP - STAB is used to turn the antenna stabilization function on or off. SWEEP allows the selection of two distinct full scale sweep rates of 60 and 120 degrees. The FRZ (freeze) Mode, when enabled, freezes the display in its last updated position.

4.1.3 The Transponder Beacons

The transponder beacons used during the Airborne Radar Approach testing were manufactured by the Motorola Co., Model SST-181 X-1. The transponder beacons operate at a receive frequency of 9375 MHz and a transmit frequency of 9310 MHz. They have a power output of 400 watts. The transponder beacons were powered by a series of twelve volt lead-acid

batteries mounted on a small cart. Figure 4.6 shows the transponder beacon mounted in a portable, water-tight case.

4.1.4 Flight Test Helicopter

The aircraft utilized for the Airborne Radar Approach (ARA) flight test program was a NASA Sikorsky CH53A helicopter (N-39) as shown in Figure 4.7. This type of aircraft normally cruises at 140 kts and is primarily used by NAFEC and NASA for flight test purposes. The test aircraft was based out of NAFEC in Atlantic City, New Jersey.

The CH53A helicopter is a fully operational IFR aircraft. Both the pilot and copilot have full sets of operating flight controls and instruments. The center console houses control heads for single UHF and HF, and DUAL VHF communications systems, along with DUAL Collins NCS-31A RNAV systems. The front panel contained various instruments including a flight director, HSI, RMI, Radar and Barometric altimeters.

4.2 TEST PROFILES AND PROCEDURES

Twenty-five flights were flown in the Airborne Radar Approach (ARA) flight test program at NAFEC in Atlantic City, N.J. The twenty-five flights flown involved utilizing two distinct radar systems, various track orientation techniques and operational modes. Of the twenty-five flights, ten were performed in the multiple beacon mode using two longitudinally spaced beacons during the testing period from 1 January 1979 to 2 February 1979 with one additional flight accomplished on 7 August 1979. Table 4.1 presents the Bendix RDR-1400A multiple beacon flight test matrix, showing test location, beacon spacing and total number of approaches flown. Five of the twenty-five flights flown utilized the RCA Primus-50 radar system. The testing using the Primus-50 involved Brandywine lighthouse (offshore site) where two operational modes were tested during the period from 26 June 1979 to 29 June 1979. Table 4.2 presents the RCA Primus-50 flight test matrix, showing operational mode and number of approaches. During the period from 16 July 1979 to 30 July 1979 six of the twenty-five flights were accomplished in the skin paint and skin-paint w/cursor modes. Table 4.3 presents the Bendix RDR-1400A skin paint and skin paint w/cursor flight test matrix, showing which

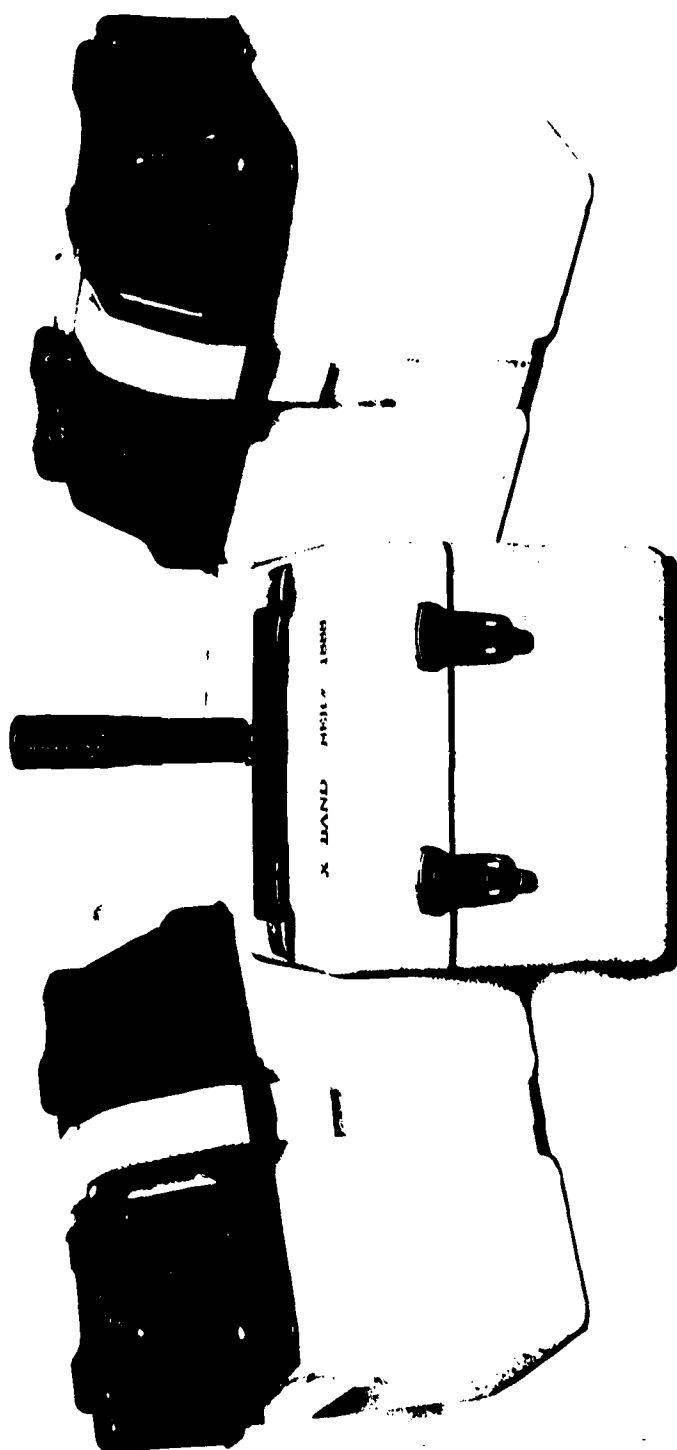


Figure 4.6 The Transponder Beacon

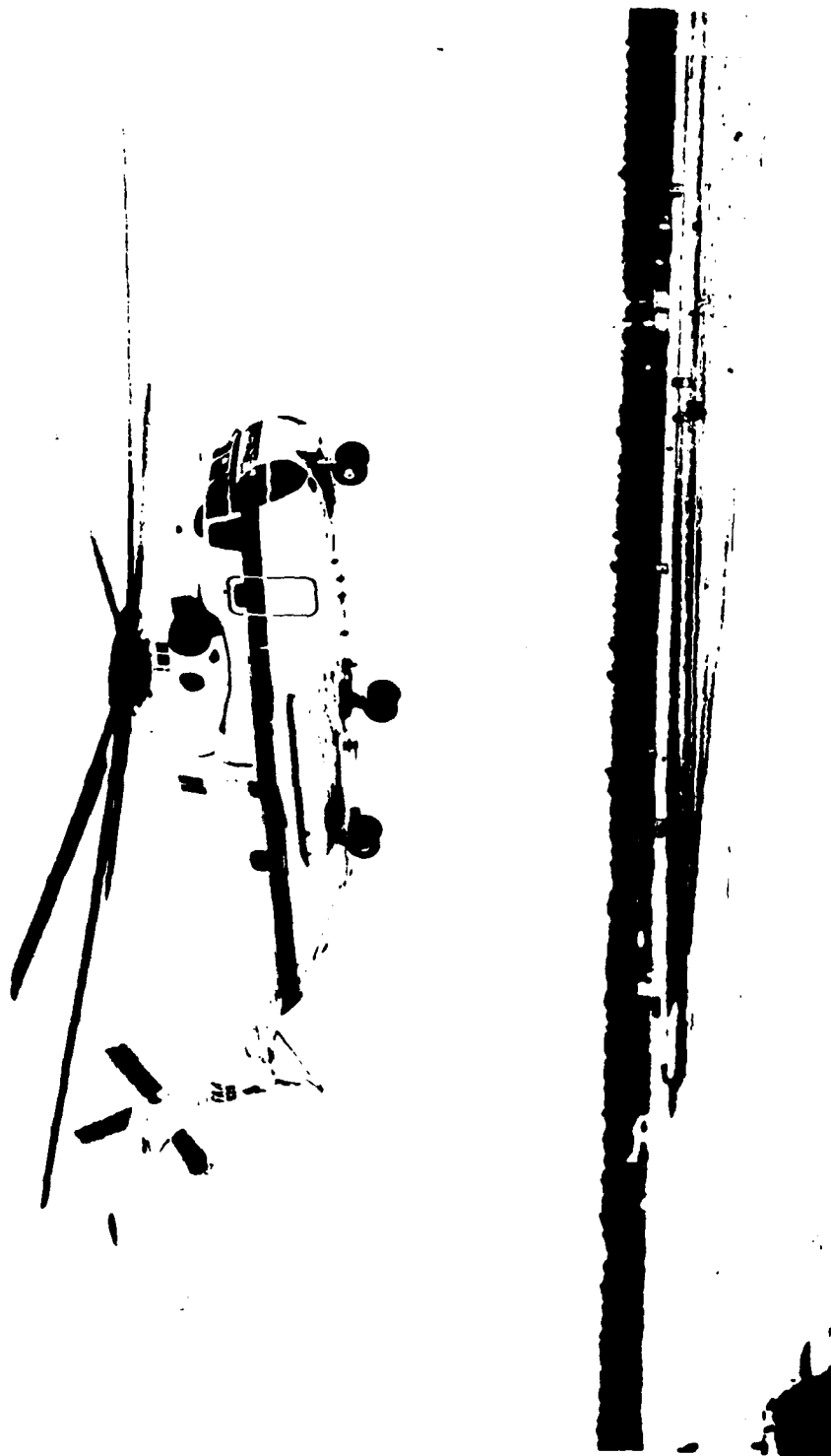


Figure 4.7 NASA Sikorsky CH53A Test Helicopter

Table 4.1 Bendix RDR-1400A Multiple Beacon Flight Test Matrix

FLIGHT	DATE	LOCATION AIRPORT SITE	BEACON SPACING	NUMBER OF APPROACHES		PILOT	COPILOT
				25 NM	10 NM		
1	1/19/79	Rwy 13	10,400'	1	3	A	B
2	1/25/79 am	Rwy 13	10,400'	1	2	A	C
3	1/25/79 pm	Rwy 13	10,400'	1	3	C	D
4	1/26/79 am	Rwy 13	5,000'	1	3	D	A
5	1/26/79 pm	Rwy 13	5,000'	1	3	C	D
6	1/31/79 am	Rwy 13	5,000'	1	3	B	C
7	1/31/79 pm	Rwy 13	15,000'	1	3	A	B
8*	2/5/79 am	Rwy 13	10,400'	1	3	A	D
9*	2/5/79 pm	Rwy 13	15,000'	1	3	D	B
10	8/7/79	Rwy 13	10,400'	1	2	C	D
Total				10	29	A-5 C-5	B-4 D-6

*Note: A 3dB attenuator was implemented on the near beacon to reduce splaying.

Table 4.2 RCA Primus-50 Flight Test Matrix

FLIGHT	DATE	LOCATION	OPERATING MODE	NUMBER OF APPROACHES		PILOT	COPILOT
				25 NM	10 NM		
1	6/26/79	Offshore	Combined	1	2	D	C
2	6/27/79 am	Offshore	Combined	1	2	C	B
3	6/27/79 pm	Offshore	Combined	1	2	B	D
4*	6/29/79 am	Offshore	Combined/ Beacon-Only	1	3	C	B
5	6/29/79 am	Offshore	Beacon-Only	1	3	B	D
		Total	Combined	4	7	A-0	B-4
			Beacon-Only	1	5	C-3	D-3

*Note: Two approaches were flown in the combined mode and two in the beacon-only mode.

flights were flown utilizing the new cursor technique, location, and total number of approaches. The remaining four flights were flown at the airport site using the modified Bendix radar system in the beacon with cursor mode. These four flights were accomplished during the period from 2 August 1979 to 6 August 1979. Table 4.4 presents the Bendix RDR-1400A single beacon w/cursor flight test matrix, showing type of profile flown, location, and total number of approaches.

Table 4.3 Bendix RDR-1400A Skin Paint and Skin Paint W/Cursor Flight Test Matrix

FLIGHT	DATE	LOCATION	OPERATING MODE	NUMBER OF APPROACHES		PILOT	COPILOT
				25 NM	10 NM		
1	7/16/79	Offshore	W/O Cursor	1	2	C	D
2	7/17/79 am	Offshore	W/O Cursor	1	2	D	C
3	7/17/79 pm	Offshore	W/O Cursor	1	2	C	D
4	7/19/79	Offshore	W/Cursor	1	2	D	C
5	7/27/79	Offshore	W/Cursor	1	2	D	C
6	7/30/79	Offshore	W/Cursor	1	2	C	D
Total			W/O Cursor	3	6	A-0	B-0
			W/Cursor	3	6	C-6	D-6

4.2.1 General Pilot Procedures

The pilot procedures which were used took into account airspace requirements, obstruction clearance and noise abatement considerations. During the tests the copilot was hooded and the pilot was unhooded. Prior to take-off, the pilot input RNAV waypoint coordinates to aid in getting established on the desired approach course. Upon completion of the procedure turn inbound and just prior to reaching the Initial Approach Fix (IAF) inbound, the copilot took over navigation using the airborne radar. It was the copilot's responsibility to call out heading (e.g., turn to heading 180°) and/or heading changes so that the pilot

Table 4.4 Bendix RDR-1400A Single Beacon W/Cursor Flight Test Matrix

LOCATION	AIRPORT SITE										NUMBER OF APPROACHES	PILOT	COPILOT	DATE FLOWN	
	PROCEDURE	DIRECT STRAIGHT			OVERHEAD STRAIGHT			INTENTIONAL OFFSET							
Segment Length nm		25	5	25	5	25	5	25	5	25	5				
Runway		26	08	26	08	26	08	26	08						
Flight															
1		X	X	X	X							4	C	D	8/2/79 am
2						X	X	X	X			3	D	C	8/2/79 am
3		X				X		X	X	X		4	C	D	8/2/79 pm
4										X	X	3	D	C	8/6/79
Total		2	1	1	1	1	2	3				14	A-0 C-4	B-0 D-4	

could maintain the desired track. It was also the copilot's responsibility to call out range from the target at one mile intervals and altitudes depending on which profile was flown. On reaching the Initial Approach Fix, the copilot called out range and altitude so that the pilot could start a descent and cross the Final Approach Fix (FAF) not less than 500' Above Ground Level (AGL). After crossing the IAF and stabilizing, a specified rate of descent was established and the airspeed was decreased to 90 knots. On crossing the Final Approach Fix (FAF), a descent was established so that the Minimum Descent Altitude (MDA) would be reached at no less than one half ($\frac{1}{2}$) mile from the landing area. Again, after the rate of descent was established, the airspeed was then decreased to 50 knots and held there until either the landing area was in sight or a missed approach was executed. If the landing area was not in sight, the copilot called out "missed approach", at which time the missed approach procedures were executed. The missed approach executed was indicated on the approach plate used. It consisted of a climbing right or left turn to 1000' to intercept the Initial Approach Fix. The pilot's other duties included radio communications and watching out for traffic. It should be noted that even though the pilot flew unhooded he was instructed to fly only those headings and heading changes indicated by the copilot. Figure 4.8 presents the Airborne Radar Approach geometries for both the airport and offshore sites.

4.2.2 Bendix RDR-1400A Multiple Beacon Testing

The effort in this portion of the testing was concentrated on using two independent ground beacons to establish visual reference indications of the desired final approach course on the airborne radar display. It is the functional equivalent of the multiple-reflector technique used in the ground mapping mode. Ten flights were accomplished in the multiple beacon testing and of these ten flights six were non-recoverable from the film interpretation standpoint because of beacon splaying. Although not known during the testing, it was later discovered that the STC circuit in the Bendix radar system was improperly adjusted. The testing accomplished after the adjustments were made verified this fact to some extent, but it was still found necessary to constantly adjust the gain control throughout the approach.

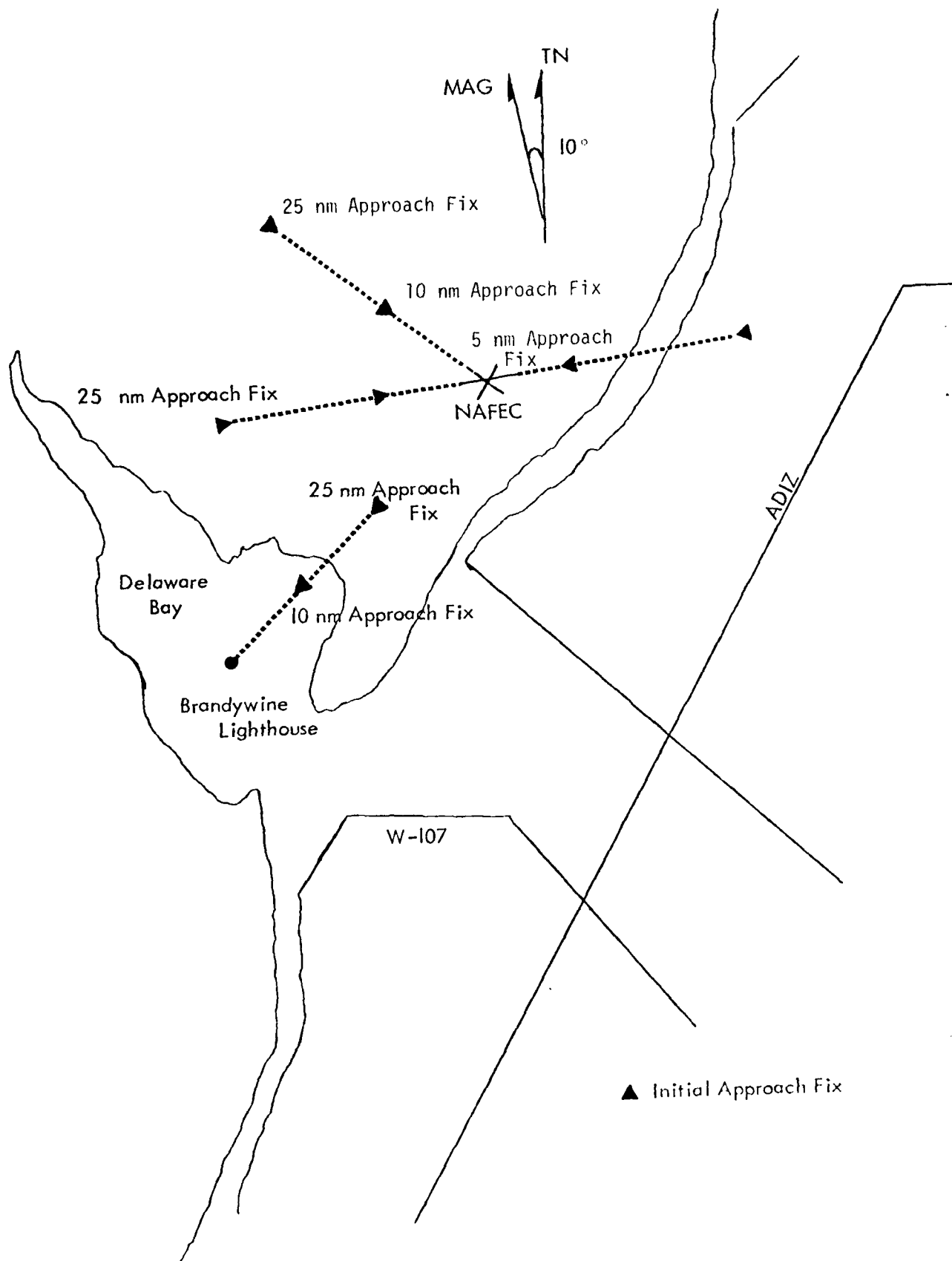


Figure 4.8 Airborne Radar Approach Geometries

The double beacon technique has applications primarily to landside sites only. Therefore, the airport site was utilized as the testing site. Runway 13 was picked because it allowed large longitudinal distances for beacon placement. During the double beacon testing, beacon separation was included as a controlled variable, with one beacon permanently positioned at the target landing zone (threshold of runway 13) and the other positioned in line with the final approach course (runway centerline) at varying distances beyond the first.

The procedures utilized were identical to those used during the single beacon approach testing from October 1978 to December 1978. Pilot procedures, as described in Section 4.2.1, and profiles were generated in advance to offer the test program a controlled environment. The test profile flown was the direct straight profile as shown in Figure 4.9. This direct straight procedure was utilized quite extensively during the single beacon approach testing (Reference 1) conducted at the airport, remote and offshore sites. Normally the direct straight procedure is used when the winds are favorable for landing upwind in the approach direction.

4.2.3 RCA Primus-50 Combined and Beacon-Only Mode Testing

Five data flights were flown at the offshore site in the combined and beacon-only modes using the RCA Primus-50 radar system. All of the data flights flown were of acceptable quality with the exception of the first where it was found necessary to omit the first two approaches from the data base due to instrumentation difficulties. The combined mode feature of the Primus-50 offers the capability of mapping both beacon and ground returns simultaneously. This mode of operation was included as a requirement in the draft ARA MOPS (Minimum Operational Performance Standard) generated by RTCA SC-133. This series of flight tests supplied data to formulate a combined and beacon-only mode data base suitable for comparison to that established during the extensive testing performed in the single beacon mode using the Bendix System from October 1978 to December 1978.

The procedures for the Primus-50 testing utilized the direct straight procedure at the offshore site. The offshore site was chosen because

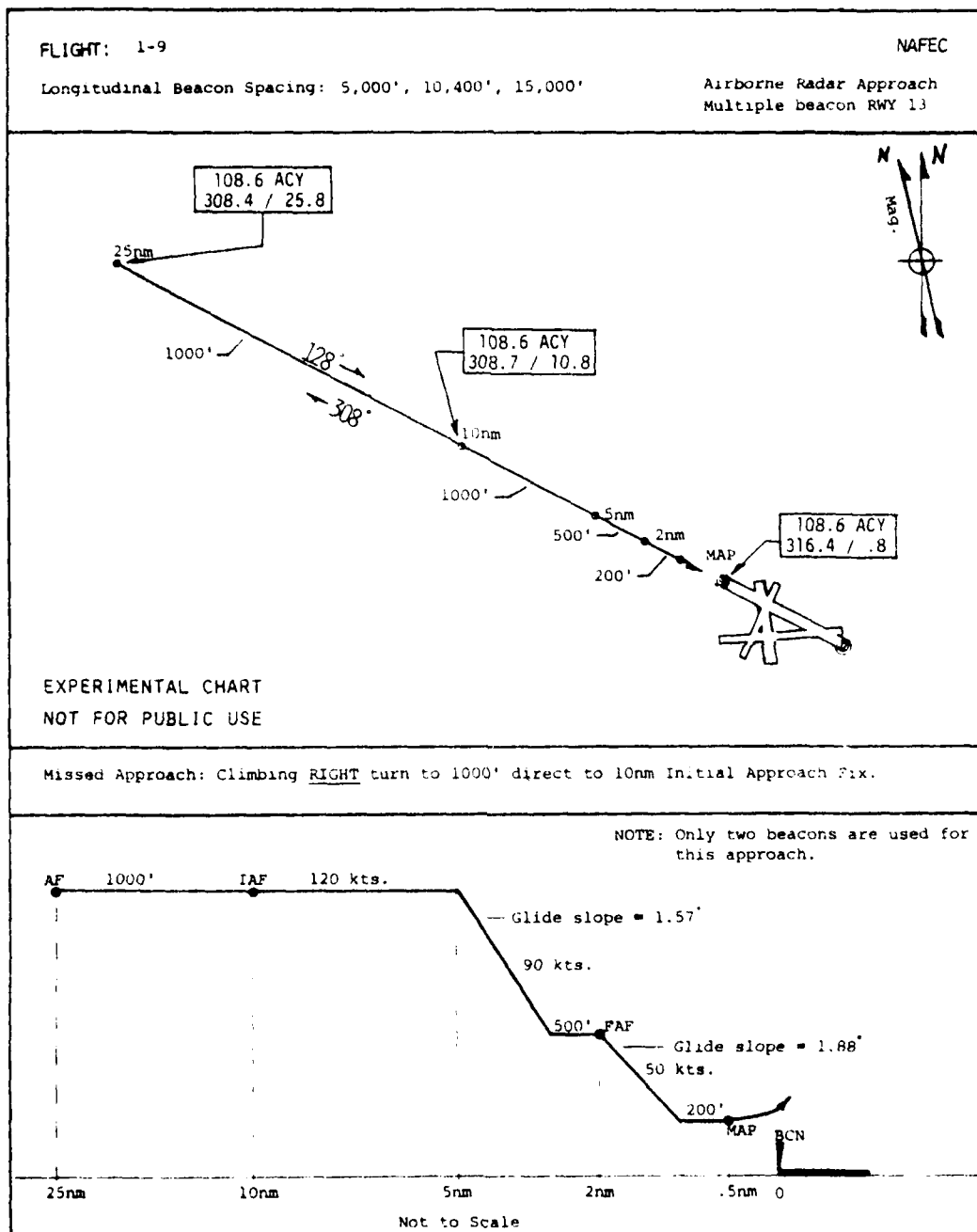


Figure 4.9 Bendix RDR-1400A Multiple Beacon Direct Straight Procedure

it offered sufficient skin paint targets necessary to determine the operational feasibility of the combined mode. Figure 4.10 presents the approach plate used during the Primus-50 testing. As before, the direct straight procedure was utilized for the descent profile. RNAV waypoint coordinates were established to aid the pilot in getting established on the proper approach course. One difference should be noted between the multiple beacon procedure (Figure 4.9) and the Primus-50 procedure. Instead of using the 10 nm IAF as the RNAV waypoint, as was the case in the multiple beacon tests, the RNAV waypoint was established as a fix 12 nm from the intended target. This extra 2 nm gave the pilot time to get established on the final approach course before handing off navigation to the copilot.

4.2.4 Bendix RDR-1400A Skin Paint and Skin Paint W/Cursor Testing

The effort in this portion of the testing was to use a prominent surface object (Brandywine Lighthouse) to simulate Airborne Radar Approaches to offshore sites with and without the aid of a cursor. The testing performed included six data flights and all were considered to be of very acceptable quality. During previous skin paint testing, local shipping occasionally created confusion on the part of the operator. The previous tests performed also offered no quantitative data so that the overall accuracy could be determined. These six flights flown from 16 July 1979 to 30 July 1979 offered a data base large enough to compare single beacon versus skin paint results at offshore sites and to also determine to what degree the pilot is aided by the use of a cursor in such an environment. As mentioned earlier the modified Bendix radar system offers the presentation of a cursor display electronically generated from the OBS setting on the HSI. The purpose of the cursor is to reduce the "homing" effect caused by the lack of track orientation information presented on the radar screen. In most of the skin paint testing the SRCH 2 mode was used because of its high resolution at all ranges in small sea states.

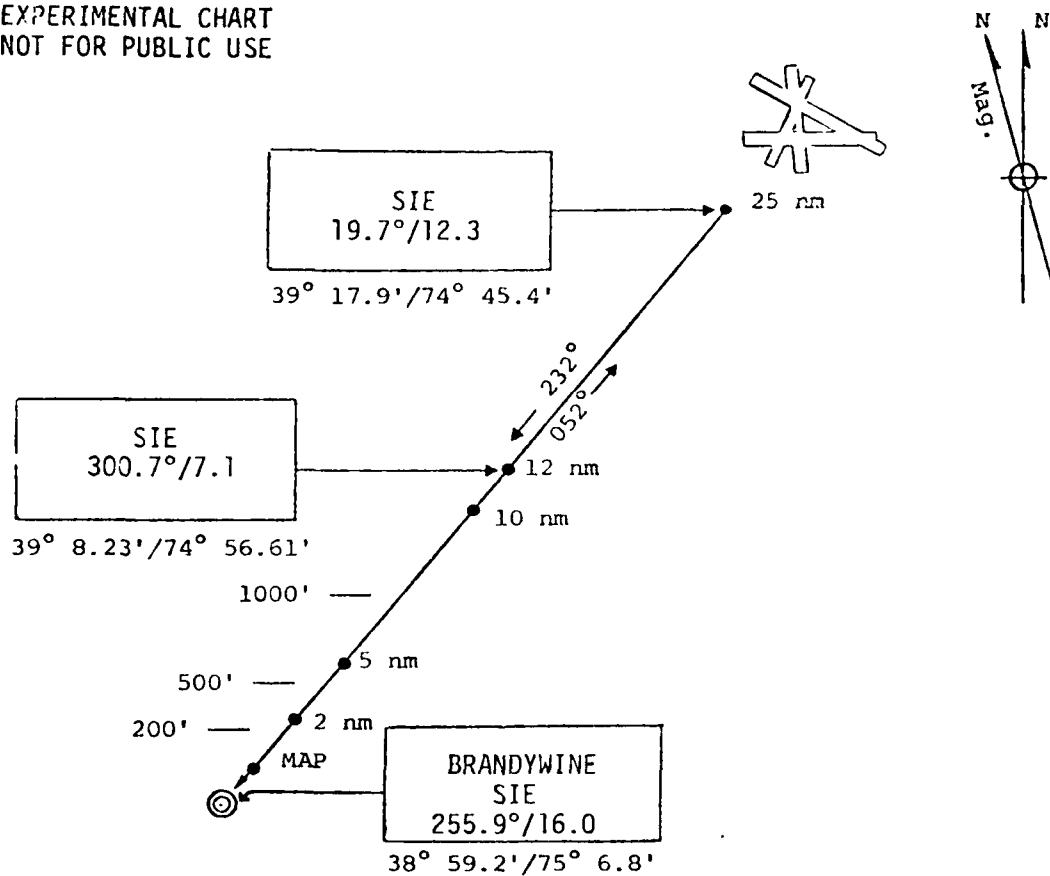
The same basic procedures were utilized in the skin paint testing that were used in the Primus-50 testing. The direct straight procedures were used and also the same waypoints were utilized for track acquisition.

MODE:

- Single Beacon only
- Combined

Brandywine Lighthouse
VOR 114.80 Mh SIE
Airborne Radar Approach

EXPERIMENTAL CHART
NOT FOR PUBLIC USE



MISSED APPROACH: CLIMBING TURN TO 1000' DIRECT TO 12 NM RNAV WP.

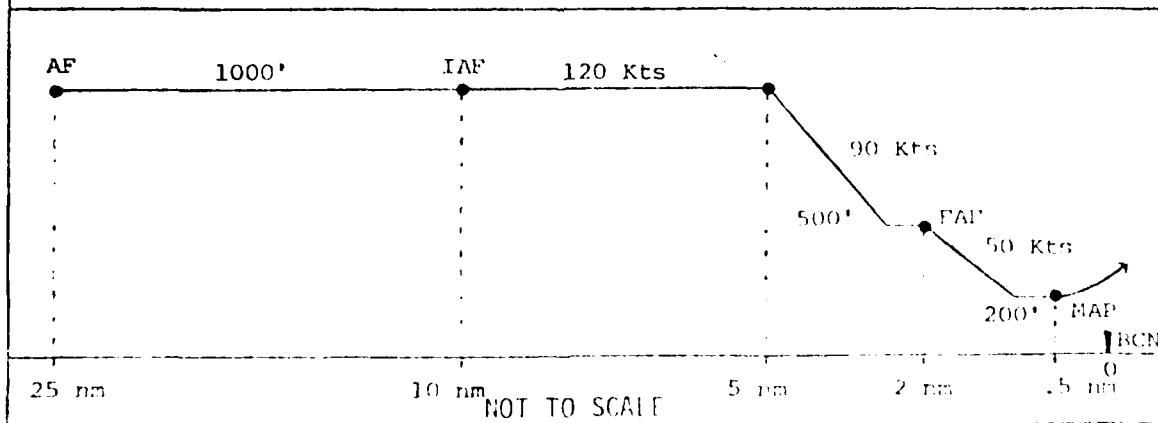


Figure 4.10 RCA Primus-50 Offshore Direct Straight Procedures

Figure 4.11 presents the approach procedures utilized during the Bendix RDR-1400A offshore skin paint and skin paint with cursor testing. The same procedures were used so that a direct correlation of results could be made possible.

4.2.5 Bendix RDR-1400A Single Beacon With Cursor Testing

The single beacon with cursor testing consisted of four flights, with a total of fourteen approaches. Of these fourteen approaches two were not recoverable due to film processing difficulties. Two different types of approaches were conducted at the airport site providing a reasonable data base so that cursor aided approaches could be compared to non-cursor aided approaches. As in the other areas of testing, pilot procedures and profiles were generated in advance in order to insure a well disciplined test environment.

The procedures used during this phase of testing were identical to those described in Section 4.2.1. Figures 4.12 and 4.13 show the direct straight and overhead straight approach profiles flown with their associated plan views. The procedures used for flying the two profiles were identical, with one exception. On the overhead approaches it was necessary for the copilot to call out when directly overhead the target so that the pilot could start an outbound timing of 2½ minutes. At the end of 2½ minutes, a procedure turn was executed and the Intermediate Approach Course was acquired. The overhead offset procedure was not utilized during this phase of testing because of the limited number of flights. The inclusion of the overhead offset approaches would have increased the data base to an unacceptable level with the available sampling.

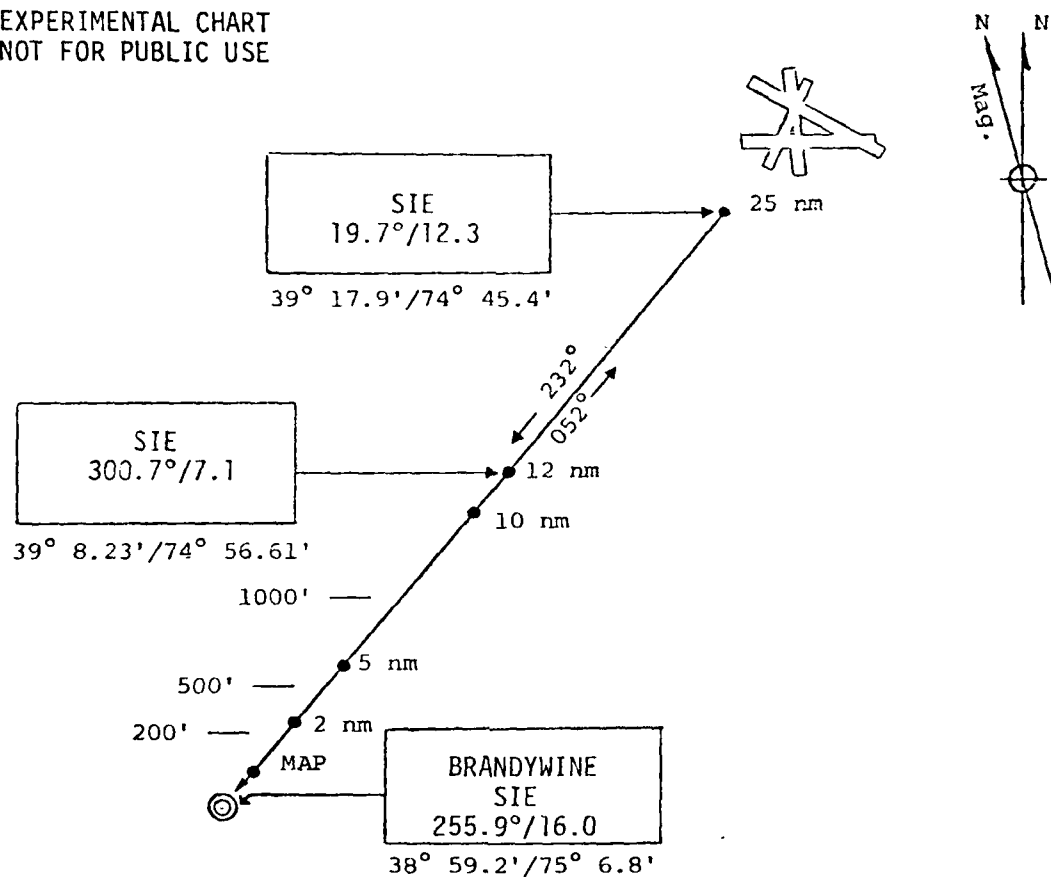
During the single beacon with cursor testing a new test variable was introduced. It involved intentionally offsetting the aircraft from the beginning of the approach, based on specific instances of aircraft placement discovered during the analysis of the data collected during the single beacon approach testing. The purpose of the intentional offset procedure was to determine the effectiveness the cursor technique. That is, can the radar operator acquire the intended course

MODE:

- Skin Paint Only
- Skin Paint With Cursor

Brandywine Lighthouse
VOR 114.80 Mh SIE
Airborne Radar Approach

EXPERIMENTAL CHART
NOT FOR PUBLIC USE



MISSED APPROACH: CLIMBING TURN TO 1000' DIRECT TO 12 NM RNAV WP.

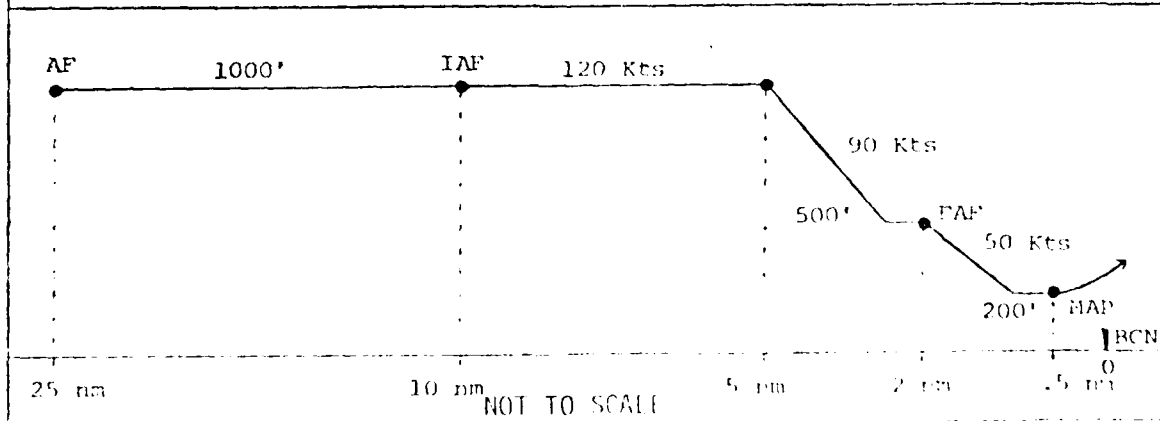


Figure 4.11 Bendix RDR-1400A Offshore Direct Straight Procedures

MISSED APPROACH:

Climbing Turn (Left or Right)
to 1000' then intercept
Initial Approach Course

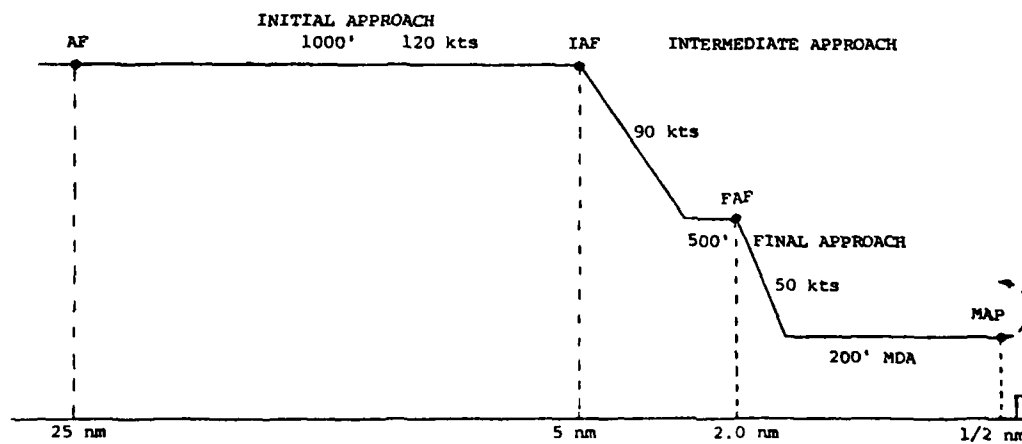
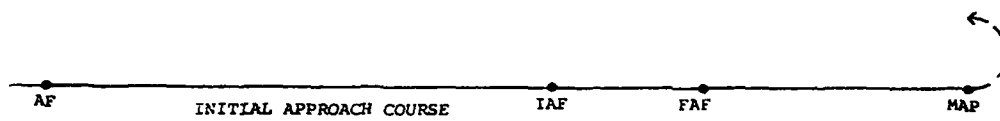


Figure 4.12 Profile 1: Direct Straight Airport Site

MISSED APPROACH:

Climbing Turn (Left or Right)
to 1000' then intercept
Initial Approach Course

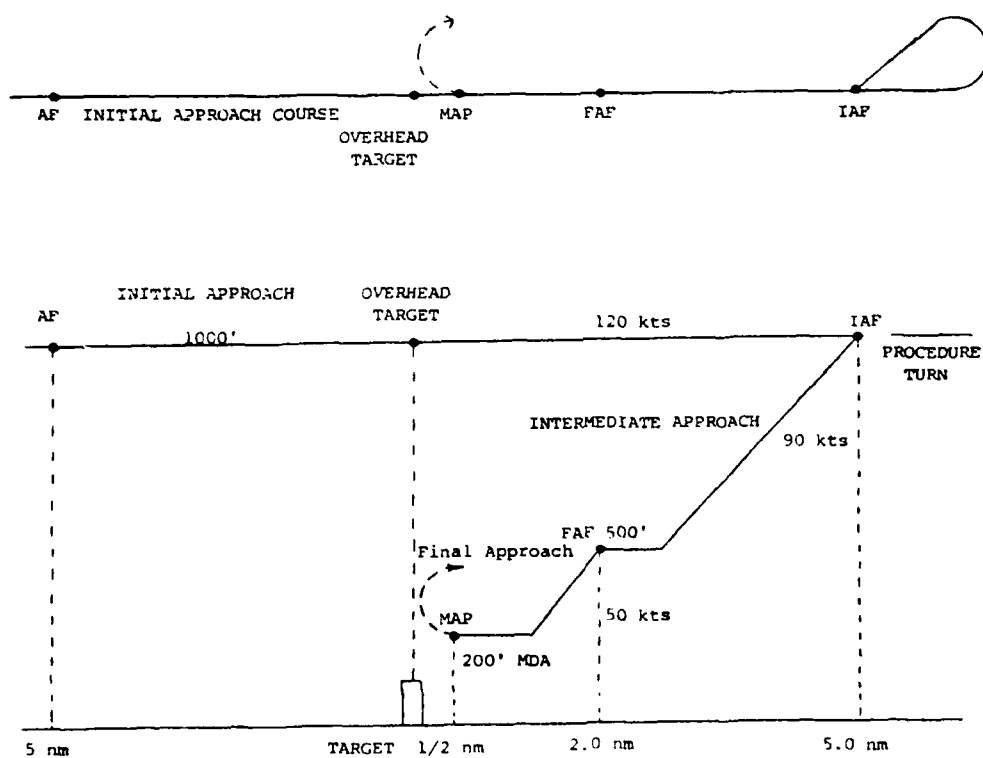


Figure 4.13 Profile 2: Overhead Straight Airport Site

using the cursor and track it inbound without homing to the target. Due to film difficulties only one of the intentional offset approaches was recoverable. The tracking plot for the earlier approach selected as a comparison for the intentional offset profile can be seen later in Section 5.0.

Only one beacon transmitter was installed for this test series. The beacon transmitter was located at the threshold of runway 26 regardless of approach direction.

4.3 SUBJECT PILOT EXPERIENCE AND TRAINING

Four subject pilots were used for the Airborne Radar Approach flight test program using various track orientation techniques. All four pilots alternated as pilot and copilot during part of the test program. Due to the retirement of one subject after the completion of the multiple beacon testing the three remaining subject pilots completed the test program. All pilots involved were FAA personnel resident at NAFEC in Atlantic City, N.J.

Proficiency in using the airborne radar came about through actual operational use. This operational use was accomplished during the skin paint and single beacon approach testing from July 1978 to December 1978. There were two pilots per crew with the copilot being the only crew member hooded. The pilot was not hooded for safety reasons, but was instructed to fly only those course headings indicated by the copilot. It was also the pilot's responsibility to handle all communications. A summary of each pilot's experience level is presented in Table 4.5.

Table 4.5 Flight Experience of Subject Pilots In Hours

Subject Pilot	Total	Rotary Wing	Fixed Wing	CH53A
A	11,500	4,500	7,000	55
B	16,010	415	15,595	125
C	17,000	1,500	15,500	160
D	17,175	1,800	15,375	115

4.4 DATA ACQUISITION AND PROCESSING

This section describes the methods used to instrument, record, recover, and process the flight test data for the Airborne Radar Approach testing.

4.4.1 Airborne Instrumentation

The airborne instrumentation consisted of electronically recording selected parameters using a Litton LTN-51 Inertial Navigation System (INS) interfaced with a Kennedy magnetic tape recording system on the multiple beacon program and a Norden MZ-RX11-DB Dual floppy disc drive recording system on the later cursor aided approach testing. The following parameters were recorded: time, latitude, longitude, ground speed, true heading, and track angle. In addition to recording inertial position data, the radar screen itself was photographed along with a digital display of time and aircraft magnetic heading. The film data provided the simultaneous recording of many parameters such as: time, heading, beacon position relative to zero azimuth, scale, sweep, tilt, and gain. The optimum photographic recording rate was determined to be one frame every two seconds. Other rates were tried but were found to be inadequate due to the limited amount of film available on each cartridge, or due to insufficient data recording frequency.

4.4.2 Ground Reference Data

The ground reference data was obtained using the NAFEC "Extended Area Instrumentation Radar" (EAIR). The EAIR radar was utilized as the indicator of actual aircraft position, by detecting and recording (real time) the azimuth, elevation and range of the test aircraft. EAIR is a precision, C-band tracking radar which provides the slant range, azimuth angle and elevation angle of an aircraft within a range of 100 nautical miles when operating in the skin tracking mode, with a maximum distance of 190 nautical miles when operated in the beacon tracking mode. (All of the ARA test flights were tracked in beacon tracking mode). The slant range obtained by the EAIR facility is accurate within 20 yards and the azimuth angle and elevation angle are accurate within 0.011 degrees. For example, at 50 miles the

accuracy would be 20 yards in range and 20 yards in azimuth and elevation. The radar antenna can track a target 360° in azimuth and from 0° to +89° in elevation. The antenna can be directed as low as minus one and one-half degrees in elevation.

4.4.3 Manually Recorded Flight Logs

During all flights a trained cockpit observer monitored and kept an accurate log of routine and special events that occurred during the flight. The observer was responsible for documenting the crew workload and performance. The flight logs recorded by the observer were a major source of data acquisition from which flight test results could be operationally evaluated. The following is a summary of the flight test data recorded by the observer during each flight.

- 1) Procedural Errors
- 2) Elapsed Time
- 3) Altitude
- 4) Airspeed
- 5) Aircraft Heading
- 6) Radar Approach Distance
- 7) Radar Mode
- 8) Radar Range Scale
- 9) Radar Gain Position
- 10) Radar Tilt and Stabilization
- 11) Pilot Workload

4.4.4 Data Processing

The airborne and ground-derived position tracking data were used to determine the capability of an airborne radar approach procedure to guide a helicopter along a predetermined approach path to a target using various types of track orientation techniques. To logically evaluate this capability, the following basic group of measures were computed for each test approach:

- 1) Helicopter deviation from the intended track
(the track to be defined by an inbound bearing
to the runway threshold or landing zone).

- 2) Radar sensor error in both the along track and cross track directions.
- 3) Flight technical (FTE) which is a measure of pilotage error in the cross track direction at all ranges.
- 4) Letdown error (LDE) which is a measure of pilotage error in the along track direction at step down fixes. LDE quantifies the pilot's ability to identify the step down fix from the radar display.

The raw flight test data was reduced according to the following steps:

- 1) A projected preview of each film was performed to identify the targets, before digitization of the photographic data.
- 2) The relevant photographic data was then recovered by projecting the data on a digitizer tablet which was interfaced with a computer. In addition, data read from each frame such as time and heading was also inputted. The overall return dimensions were recovered wherever possible, since return size and shape played an important role in pilot orientation during each approach.
- 3) While digitizing, computer routines were used to convert digitized points to radar range and azimuth coordinates.
- 4) The file was then transmitted via dataphone to the time sharing system, where NAFIC LAIR and INS data tapes had also been sent for processing.

5) The airborne data was then merged with the tracking information to produce a complete data file from which navigation error measures were derived. EAIR tracking was the primary source of ground truth data, but on some approaches to the offshore site EAIR tracking was lost due to low altitude, in which case the INS had to be used. In those cases it was necessary to perform a three-way merge. When the three-way merge was complete, EAIR tracking dropout times were matched with the original EAIR tracking and INS printouts. Using these dropout times, the corresponding EAIR latitudes and longitudes were noted. In order to remove the effects of INS drift, differences in latitudes and longitudes were computed by subtracting the EAIR tracking values from the INS values.

$$\Delta \text{lat} = \text{lat (EAIR)} - \text{lat (INS)}$$

$$\Delta \text{lon} = \text{lon (EAIR)} - \text{lon (INS)}$$

These values were then supplied to the error analysis program, which used the three-way merge as the input file. This program then sequenced from EAIR to INS as the position standard at the times manually arrived at earlier. The program also makes use of the lat/lon correction factors, and interpolates linearly between the two corrections to yield an INS correction factor for each data point. When the merge was complete, navigation errors were computed. These were as follows: Total system cross track error, flight technical error, airborne system cross track error and airborne system

along track error. The precise definition of these error quantities is specified in Section 4.5.1. The statistical treatment of these error quantities will be discussed in Section 5.

- 6) Due to abnormal hardware difficulties on a few approaches a time correlation problem was encountered between the tracking data and the airborne data. To resolve this problem it was necessary to derive track angle along the approach path from the EAIR tracking data. Then a plot was generated of track angle versus time for both the EAIR tracking and INS data. When the plots were completed the data was correlated and the time correction factor noted. This time correction factor was then added or subtracted to the airborne data depending on the direction of the time shift. Figure 4.14 presents typical plots from which time correlation factors were obtained.

Afterwards, the data was then merged with the ground reference data.

Observer log data as well as pilot and copilot workload ratings were also evaluated for each approach.

4.4.5 Data Processing Facilities

Data processing was accomplished using a combination of a dedicated microcomputer system resident at the SCI (Vt.) facility, and a remote time-sharing system. Data was recovered using a Summagraphics digitizer tablet interfaced with a 48K Byte North Star microcomputer system. The digitized data, along with the parametric data read from each frame (time, heading, scale factor, sweep angle) keyed in from a CRT terminal, was stored on disk. Once complete files of data for each test were assembled, they were transmitted by direct computer data interchange to the CDC Cybernet system. The Cybernet was then used to load the INS and EAIR tapes, perform the merge step, and then perform the error measure derivation and statistical analysis steps.

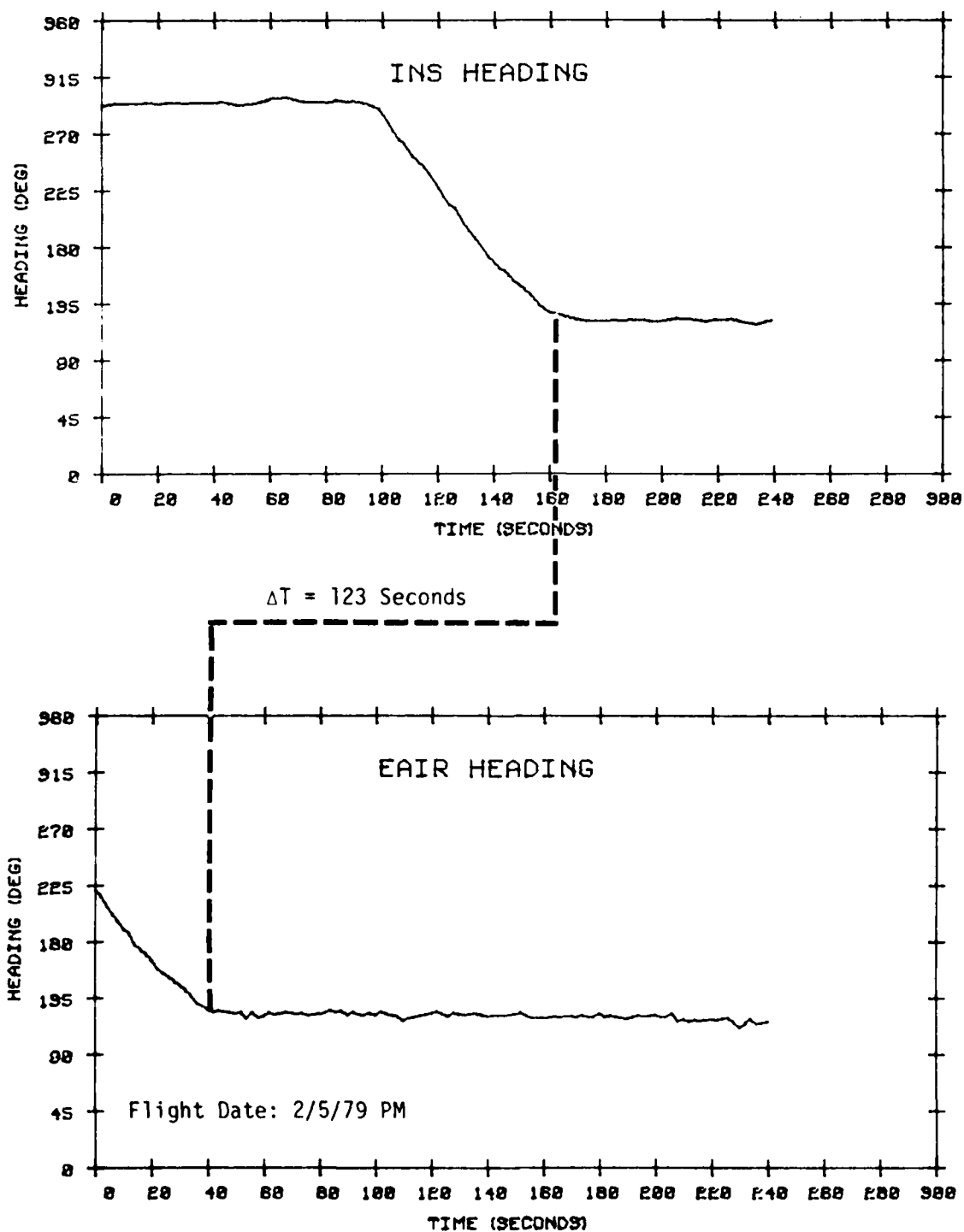


Figure 4.14 Time Correlation Correction Plots

4.4.6 Data Digitizing

To automate data recovery and reduce both the manual effort and the inherent potential for error, a digitizer tablet was used. Interfaced with a computer and using X-Y coordinates, the tablet allows direct entry of a broad range of data types (graphs, plans, maps, photographs, etc.) with a high degree of resolution. This technique was used with an image of each frame of film photographed in the ARA tests projected directly onto the tablet itself.

Exact registration with the tablet coordinate system was not necessary, and the problems associated with scale maintenance were eliminated, since the computer algorithm makes the necessary scale and registration adjustments frame by frame. For instance, several reference points on the CRT image (e.g., range marks) were first digitized by touching the tablet stylus to those several points in a pre-determined order. The computer then calculated scale and registration factors for that frame. The operator could then digitize the endpoints of the radar target, resulting in accurate measures of target azimuth, range and size.

4.5 DATA ANALYSIS PROCEDURES

Based on the defined intended track, the actual range/azimuth and cross track error were computed, along with airborne system error (radar and heading sensor error), and flight technical error (FTE). The production of the measures permitted a statistical analysis of each approach segment. An overall review and statistical aggregation was the result of this data processing; also plots were generated depicting the same information represented in the statistical analysis. The sample size for these quantities was determined by the number of film data points collected. It should be noted though that some data presented in Section 5.0 includes a count of the number of film data points collected and the number of approach segments flown. An outline of the data included in this report is presented in Table 4.6.

4.5.1 Navigation Error Analysis

Three measures of navigation error are desired: total system error (as measured by the CAIK and INS tracking systems), flight

Table 4.6 Data Processing and Analysis Outline

● MEASURE: TOTAL SYSTEM ERROR (along track and cross track)

Source

- EAIR Tracking Radar Data
- INS Platform Data
- Desired Track Parameters

Presentation

- Plots of Actual Track vs Desired Track
- Histogram of Total System Error

Statistical Analyses

- Mean
- Standard Deviation

Applications

- TERPS Protected Airspace
- Comparison of Enhancement Modes

● MEASURE: LFTDOWN ERROR (along track)

Source

- EAIR Tracking Radar Data
- INS Platform Data
- Airborne Radar Distance to Landing Zone
- Step-down Fix Distance
- Aircraft Altitude
- Time Synchronization

Statistical Analyses

- Mean
- Standard Deviation

Applications

- TERPS Fix Displacement Error

● MEASURE: FLIGHT TECHNICAL ERROR (cross track)

Source

- EAIR Tracking Radar Data
- INS Platform Data
- Airborne Radar Data
 - range
 - azimuth
- Aircraft Heading
- Aircraft Altitude
- Time Synchronization

Presentation

- Plots of FTE as a Function of Range to Landing Zone
- Histogram of Flight Technical Error

Statistical Analyses

- Mean
- Standard Deviation

Application

- Certification Error Budget

● MEASURE: AIRBORNE SENSOR ERROR (along track and cross track)

Source

- Total System Error
- Flight Technical Error

Presentation

- Plots of Sensor Error vs Range to Landing Zone
- Histogram of Sensor Error

Statistical Analyses

- Mean
- Standard Deviation

Applications

- Certification Error Budget

● MEASURE: BEACON PROXIMITY DATA (range and azimuth)

Source

- Airborne Range to Landing Zone
- Beacon Presentation on Radar Display (target size)

Presentation

- Beacon Image Size vs Range to Landing Zone (sensitive to gain setting)

Applications

- Operational Evaluation of Enhanced Targets
- Beacon Presentation Certification Data
- Display Resolution for SC-133

● MEASURE: AIRBORNE RADAR RANGE DATA

Source

- Airborne Radar Presentation

Presentation

- Maximum and Minimum Airborne Range vs Site (dependent upon gain setting)

Application

- SC-133 Requirement and FAA Certification Specification

● MEASURE: PILOT PROCEDURES AND BLUNDER ERROR DATA

Source

- Tracking Radar Data
- Observer Log

Presentation

- Blunder Type vs Operational Procedure
- Count of Procedural Error and Blunder by Type

Application

- Workload Assessment
- Operational Procedures Evaluation
- TERPS Protected Airspace Requirements
- FAA and SC-133 Specific Radar Design Requirements

technical error, and airborne system (radar and heading combination) error. These quantities were calculated from the measured parameters in the following manner:

TOTAL SYSTEM ERROR -- Total system error is the deviation of the aircraft from desired track (in the cross track direction) as measured by the tracking system (EAIR). After appropriate coordinate conversions, actual aircraft range (r_0) and bearing to the target (θ_0) were calculated given target coordinates, intended track bearing (θ_t) and aircraft position. Total System Cross Track Error (TSCT) and Total Along Track Distance (TATD) were calculated as follows:

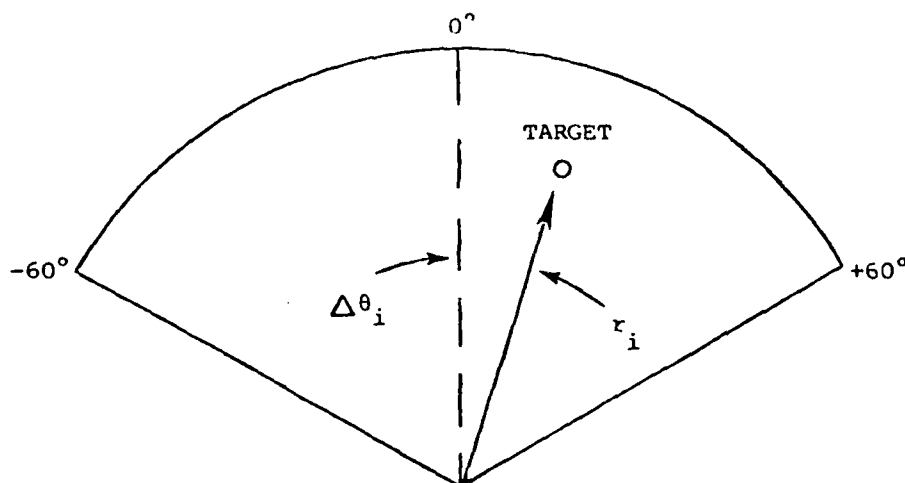
$$\text{TSCT} = r_0 \sin (\theta_0 - \theta_t)$$

$$\text{TATD} = r_0 \cos (\theta_0 - \theta_t)$$

FLIGHT TECHNICAL ERROR -- FTE is defined as the indicated deviation from desired course in nautical miles. The radar does not directly display this value, and so the pilot must deduce the indication from available parameters: radar range, (r_i) and azimuth (θ_i) to the target (landing zone) and aircraft heading (θ_h), plus knowledge of desired inbound track bearing (θ_t). Since the antenna boresight is in line with aircraft heading, indicated target azimuth (θ_i) is actually derived as being

$$\theta_i = \theta_h + \Delta\theta_i$$

where $\Delta\theta_i$ is the indicated azimuth deviation from the centerline of the display (see following figure). The pilot tries to navigate the aircraft such that indicated target azimuth (θ_i) is equal to desired tracking bearing (θ_t).



When this is true the aircraft is on course. Under a zero-wind condition, if the pilot successfully acquires and flies the intended course, then $\Delta\theta_i$ will go to zero. In the presence of a cross wind, $\Delta\theta_i$ would stabilize on some finite value of crab angle if the course is properly tracked. When θ_i is not equal to θ_t , an off-course condition is indicated. The value of the FTE indication is

$$FTE = r_i \sin (\theta_i - \theta_t) \text{ (left is +)}$$

also,
$$ATD = r_i \cos (\theta_i - \theta_t) \text{ (TO is +)}$$

where ATD is along track distance to the target

AIRBORNE SYSTEM ERROR -- Cross track and along track components of airborne system navigation error were computed from knowledge of position calculated from tracking data and the indicated position of the radar/heading combination. These errors, ASE (Airborne System Error), and ATE (Nav System Along Track Error) were calculated as follows:

$$ASE = TSCT - FTE$$

$$ATE = ATD - TATD$$

An additional error component is along track pilotage error experienced when a step down fix is crossed.

Letdown Error (LDE) is defined as the difference between ATD when descent is actually initiated and the nominal along track distance of the step down fix as charted.

5.0

ANALYSIS OF RESULTS

The purpose of this section is to provide detailed insight into the flight test results and data analysis for the Airborne Radar approach flight test program utilizing various track orientation techniques. The details presented in this section present the results of a comprehensive review of the specific data collected during the flight test program.

This section is divided into four subsections of data analysis to assist in the understanding and interpretation of the primary results. These categories are:

- 5.1 AIRBORNE RADAR AS AN APPROACH AID
- 5.2 ANALYSIS OF PILOT PROCEDURES
- 5.3 DETAILED ACCURACY DATA
- 5.4 OPERATION EVALUATION OF THE ARA CONCEPT

Due to the fact that two test areas were involved — Airport and Offshore — and that six radar operating modes were tested — multiple beacon, beacon with cursor, skin paint, skin paint with cursor, combined, and beacon-only — and that three types of data are of interest — accuracy, functional and procedures — this results discussion begins in Section 5.1 with a brief summary of the major findings. This summary of results is then followed and substantiated by more detailed tabular and graphical data analysis. This data analysis has been categorized as shown above into Sections 5.2, 5.3 and 5.4 for ease of reference. Also references will be made to an earlier ARA report (October 1979) written entitled "Airborne Radar Approach System Flight Test Experiment" (Reference 1). This report will be utilized so that comparisons can be made with the results obtained during the track orientation technique flight test program.

5.1 AIRBORNE RADAR AS AN APPROACH AID

The results presented in the following discussion have been compiled from the overall analysis of ARA as an approach aid utilizing various operational modes and track orientation techniques. The purpose of this section is to highlight the data and the quantitative results which provide the most significant impact on the qualitative

conclusions reached. To this end, Section 5.1.1 discusses primary results developed in detail in Section 5.2. Similarly, Section 5.1.2 summarizes Section 5.3 etc.

5.1.1 Pilot/Copilot Procedures and Workload

Pilot ARA procedures were developed which resulted in safe approaches with acceptable cockpit workload. These procedures were compatible with current ATC operational constraints in the airport and offshore areas. The profiles and procedures utilized during the track orientation testing were virtually identical to those utilized during previous testing (Reference 1). The conceptual aspects of the flight test included utilizing one of two basic flight profiles to perform the approach. These were the direct straight and overhead straight profiles. The empirical aspects of the ARA approach procedure were in the area of pilot/copilot responsibility assignments. The crew coordination procedures combined with the flight profile procedures resulted in a calm and coordinated cockpit environment.

The pilot/copilot workload involved in flying an Airborne Radar Approach is quite heavy. Based on qualitative observations experienced during the single beacon testing, the Airborne Radar Approach was concluded definitely to be a two pilot operation. The copilot's workload consisted primarily of three distinct items:

- Radar target interpretation in relation to intended course (radar interpretation included track orientation utilizing the cursor and multiple beacon techniques).
- Operation of radar display controls
- Range and heading call-outs to the pilot

The copilot's mental workload was reduced by the use of various track orientation techniques. The skin paint with cursor, beacon with cursor, and multiple beacon approaches offered the copilot with more positive course guidance. During the course of the flight test program the pilots and copilots rated themselves on the level of mental and physical effort involved in flying each Airborne Radar Approach. The responses indicated that the approaches utilizing some type of track orientation technique offered only a moderate workload while workload ratings for

other types of approaches ranged from moderate to very high.

Another high workload situation arose for the copilot in the skin paint mode. Because of the lack of positive target identification available in this mode of operation copilot workload was high. Numerous surrounding surface objects made positive navigation difficult.

The pilot's workload was quite different from that of the copilot. It was the pilot's sole responsibility to fly the aircraft and handle all Air Traffic Control (ATC) communications. As mentioned in Section 4.2.1 the copilot was hooded during the approaches while the pilot remained unhooded. The pilot was unhooded so that he could be aware of traffic in the surrounding area, especially in the airport terminal area. The pilot's workload mainly stemmed from two items: pilot/copilot and pilot/ATC communications, and aircraft handling. Handling of the helicopter became a problem because of the slow airspeed (50 knots) in high crosswind conditions.

It was concluded from the flight tests that some type of track orientation device is required to effectively fly an ARA approach. The track guidance offered by such devices, aids in track keeping therefore reducing the level of mental workload. This reduction in mental workload allows the pilot and copilot to concentrate more on the safety of the helicopter.

5.1.2 Overall Accuracy Assessment

The detailed ARA accuracy data is presented and analyzed in Section 5.3. This section summarizes ARA accuracy using two levels of analysis. First, overall ARA accuracy statistics are presented for the four primary error measures. These measures are Total System Cross Track Error (TSCT), Flight Technical Error (FTE), Airborne System Error (ASE) and Along Track Error (ATE). These error quantities have been defined previously in Section 4.5. Second, error statistics are analyzed with respect to along track distance from the target landing zone. The one-sigma error quantities presented are quantified in linear and angular terms at one, three and five nautical mile intervals from the target landing zone.

Table 5.1 summarizes the mean and one-sigma ARA error quantities obtained during the flight test program. The data in the table includes all offshore approaches flown with the Bendix RDR-1400A radar system regardless of the approach procedure. Section 5.3 discusses the details of long and short approach segments.

Table 5.1 Overall Bendix RDR-1400A Offshore ARA Performance Summary

ERROR QUANTITY	ERROR MAGNITUDES					
	Single Beacon*		Skin Paint		Skin Paint W/Cursor	
	\bar{x} (nm)	$\pm 1\sigma$ (nm)	\bar{x} (nm)	$\pm 1\sigma$ (nm)	\bar{x} (nm)	$\pm 1\sigma$ (nm)
TSCF	-.2293	.8873	.2570	.3400	.1940	.5744
FTE	-.0273	1.0185	.0615	.6350	-.0357	.4778
ASE	-.2021	.5353	.1955	.6264	.2297	.5611
ATE	.0033	.2383	.0345	.2567	.0340	.3430

*These results were obtained from Reference 1 (Section 5.3.3).

The results presented in Table 5.1 include three different operational modes. They are: single beacon, skin paint and skin paint with cursor. The results obtained in the single beacon and the skin paint mode are not significantly different. The TSCF mean values are similar in magnitude. That is, the single beacon TSCF mean value is -.2293 nm and the skin paint TSCF mean value is .2570 nm. The one sigma single beacon TSCF value shown in Table 5.1 is .8873 nm and the skin paint one sigma value is .3400 nm. The FTE values for both areas are smaller than the TSCF values. Table 5.1 also indicates that the TSCF values are similar in magnitude for both areas (single beacon and skin paint). The single beacon FTE mean is -.0273 nm, while the skin paint FTE mean is .0615 nm. The system errors (i.e. ASE and ATE) are small for both areas of testing. The small mean and one-sigma ASE and ATE quantities indicates that the airborne radar is both reliable and repeatable.

Table 5.1 also presents the skin paint with cursor approach testing results obtained at the offshore site. The TSCF and FTE values obtained for the cursor aided approaches indicate a reduction over the TSCF and

FTE values obtained for the non-cursor aided approaches. For example, the skin paint with cursor TSCT mean presented in Table 5.1 is .1940 nm and the FTE mean is -.0357 nm. The one-sigma skin paint with cursor TSCT and FTE values are .5744 nm and .4778 nm, respectively. These data show a decrease of .23 nm in the one-sigma TSCT value over the skin paint without cursor TSCT value. The FTE one-sigma value indicates virtually the same decrease. Again, the small ASE and ATE values prove that the system performs well and is quite consistent.

Tables 5.2 and 5.3 presents the performance of the ARA as a function of distance from the target. The tables illustrate the behavior of both linear and angular errors within the five mile distance-to-go area. Table 5.2 presents the offshore TSCT linear and angular error quantities for three different areas: single beacon, skin paint and skin paint with cursor. Table 5.3 presents the offshore FTE quantities for the same three operational areas. The most obvious fact observable in Table 5.2 is that the TSCT single beacon linear errors were acceptably small ($\pm .30$ to $\pm .83$ nm) in the 1-5 nm along track region. The skin paint and skin paint with cursor TSCT linear errors were also acceptably small ($\pm .18$ to $\pm .51$ nm). The angular TSCT quantities presented in Table 5.2 were somewhat larger due to the proximity to the target, these small cross track errors produce large ($\pm 4.5^\circ$ to $\pm 16.5^\circ$) angular errors. The table indicates that the larger angular errors are in the one mile distance to the target region. Even though the angular TSCT (one-sigma) errors are fairly larger they could still be included in a $\pm 30^\circ$ cone with its origin at the MAP.

Table 5.2 ARA Offshore TSCT Linear and Angular Errors as a Function of Along Track Distance

DISTANCE TO TARGET	ONE SIGMA TSCT ERROR QUANTITIES					
	Single Beacon		Skin Paint		Skin Paint W/Cursor	
	nm	Deg	nm	Deg	nm	Deg
1 nm	$\pm .30$	± 16.5	$\pm .18$	± 10.4	$\pm .16$	± 8.9
3 nm	$\pm .66$	± 12.3	$\pm .41$	± 7.9	$\pm .36$	± 6.9
5 nm	$\pm .83$	± 9.4	$\pm .40$	± 4.5	$\pm .51$	± 5.8

Table 5.3 ARA Offshore FTE Linear and Angular Errors as a Function of Along Track Distance

DISTANCE TO TARGET	ONE SIGMA FTE ERROR QUANTITIES					
	Single Beacon		Skin Paint		Skin Paint W/Cursor	
	nm	Deg	nm	Deg	nm	Deg
1 nm	+.26	+14.5	+.25	+14.0	+.15	+8.4
3 nm	+.64	+12.1	+.48	+ 9.1	+.08	+1.5
5 nm	+.84	+ 9.5	+.45	+ 5.1	+.25	+2.8

The FTE linear and angular values presented in Table 5.3 also show relatively small linear errors. They range in value for the single beacon mode from +.26 nm at 1 nm to +.84 at 5 nm. Other linear FTE quantities presented in the table range in value from +.15 nm to +.48 nm. The angular FTE values are similar in magnitude to those seen in the TSCT table (i.e. +1.5° to +14.5°). The skin paint with cursor quantities in Table 5.3 show a marked decrease over those skin paint only values presented.

The overall assessment of the ARA operational performance in the offshore environment utilizing the Bendix Radar System was that it was quite acceptable. The skin paint phase of the testing proved acceptable, but on two occasions the wrong target was tracked down to minimums. This lack of positive intended target identification could cause serious problems as regards airspace requirements. The stated RTCA SC-133 MOPS +4.0 nm airspace requirements are quite adequate in the offshore environment if the proper target can be identified in a repeatable manner. The skin paint with cursor aided approaches showed a decrease in the TSCT and FTE linear and angular error quantities at all ranges. The cursor technique provides the operator with a type of omnidirectional course guidance not offered by the single radar return.

Table 5.4 summarizes the overall Bendix RDR-1400A airport site ARA performance. As in table 5.1 the table presents four basic error quantities (TSCT, FTE, ASE and ATT) for three specific test areas (single beacon, single beacon with cursor and multiple beacon). Inspection of Table 5.4 shows that the mean and one-sigma TSCT and FTE

Table 5.4 Overall Bendix RDR-1400A Airport ARA Performance Summary

ERROR QUANTITY	ERROR MAGNITUDES					
	Single Beacon		Beacon W/Cursor		Multiple Beacon	
	$\bar{x}(nm)$	$\pm 1\sigma(nm)$	$\bar{x}(nm)$	$\pm 1\sigma(nm)$	$\bar{x}(nm)$	$\pm 1\sigma(nm)$
TSCT	.5725	1.3593	.1520	.5676	-.2434	.5986
FTE	.6279	1.4361	.2574	.7623	-.0232	.6995
ASE	-.0554	.4715	-.1054	.4863	-.2202	.3861
ATE	.1168	.1804	.1970	.1825	.0975	.1416

*These results were obtained from Reference 1 (Section 5.3.1).

quantities are considerably larger than those TSCT and FTE quantities calculated for the beacon with cursor and multiple beacon flight test areas. The single beacon TSCT mean presented in Table 5.4 showed a value of .5725 nm with a one-sigma value of 1.3593 nm. The beacon with cursor and multiple beacon TSCT means (.1520 nm and -.2434 nm) showed over a fifty percent reduction in magnitude over the single beacon quantities. The FTE quantities indicated virtually the same results. That is, with the use of a particular track orientation technique the FTE values are reduced approximately fifty percent in both the mean and one-sigma values. The ASE and ATE quantities again are small for all of the above mentioned test areas. Typically the ASE values are never greater than -.22 nm and the ATE values are usually less than .20 nm.

Table 5.5 summarizes the airport site TSCT linear and angular errors as a function of distance from the target landing zone. The ARA error magnitudes expressed in this form further substantiate that the approaches flown in the beacon with cursor and multiple beacon modes were more accurate. That is, the TSCT one-sigma data in the single beacon mode was approximately ± 1.65 nm while the beacon with cursor data was approximately $\pm .25$ nm. At one nautical mile the cursor aided approaches showed a marked decrease in the one-sigma angular quantities with the single beacon quantity being ± 34.8 degrees and the beacon with cursor being ± 10.6 degrees. The other angular quantities presented in Table 5.5 (at 3 & 5 nm) indicate virtually the same large reduction.

Table 5.5 ARA Airport TSCT Linear and Angular Errors as a Function of Along Track Distance

DISTANCE TO BEACON	ONE SIGMA TSCT ERROR QUANTITIES					
	Single Beacon		Beacon W/Cursor		Multiple Beacon	
	nm	Deg	nm	Deg	nm	Deg
1 nm	+.70	+34.8	+.19	+10.6	+.23	+12.8
3 nm	+.63	+11.9	+.25	+ 4.7	+.40	+ 7.7
5 nm	+.65	+ 7.4	+.31	+ 3.6	+.40	+ 4.5

Table 5.6 presents the airport site FTE linear and angular errors as a function of distance to the beacon. The FTE values presented in Table 5.6 are very similar in magnitude to those TSCT values presented in Table 5.5. The single beacon FTE linear one-sigma values range from +.77 nm at 1 nm to +.65 nm at 5 nm. The FTE one-sigma linear values for the beacon with cursor approaches show a marked decrease at 1 nm (+.19 nm) and at 5 nm (+.43 nm). The multiple beacon FTE values are similar in magnitude to those beacon with cursor values presented in Table 5.6 at all range intervals. The angular quantities are again large for the single beacon approaches and comparatively smaller for the beacon with cursor and multiple beacon approaches.

Table 5.6 ARA Airport FTE Linear and Angular Errors as a Function of Along track Distance

DISTANCE TO BEACON	ONE SIGMA FTE ERROR QUANTITIES					
	Single Beacon		Beacon W/Cursor		Multiple Beacon	
	nm	Deg	nm	Deg	nm	Deg
1 nm	+.77	+37.7	+.19	+10.9	+.25	+14.2
3 nm	+.67	+12.7	+.29	+ 5.9	+.41	+ 7.9
5 nm	+.65	+ 7.3	+.43	+ 4.9	+.45	+ 5.2

In summary, the overall accuracy assessment of the ARA Bendix RDR-1400A airport data showed that the cursor aided and multiple beacon approaches offered a decrease in the TSCT and FTE values over the single beacon approaches. The data indicates that the track orientation technique

virtually eliminated the tendency to "home" to the station. As shown in the skin paint with cursor data the cursor offers an omnidirectional capability. The multiple beacon method offers a different type of track guidance but the track angle error is not directly displayed on the radar screen. The intended course line must be formed as an image by the pilot between the centers of the two displayed beacons. The data indicates that the primary airspace requirements (± 4.0 nm at the IAF and ± 1.7 nm at the MAP) established by the RTCA SC-133 MOPS are more than satisfied by the beacon with cursor and multiple beacon approaches.

The offshore RCA Primus-50 testing was conducted using Brandywine Lighthouse located in Delaware Bay. The tests were performed using the combined and beacon-only modes of operation. Table 5.7 summarizes the overall TSCT, FTE, ASE and ATE errors measured during the offshore tests. Inspection of Table 5.7 results in several conclusions. First, the TSCT one-sigma quantities are very similar in magnitude between the two different operational modes. The same fact is evident for the FTE values. The combined TSCT mean value is .1561 nm while the beacon-only TSCT mean is .2680 nm. The combined mode FTE is very small (-.0039 nm) and the beacon-only mode value is quite large (.5587 nm). The ASE values for both test areas are small while the ATE values are somewhat large for this particular radar system. The large errors are possibly the result of the large size of the displayed beacon.

Table 5.7 Overall RCA Primus-50 Offshore ARA Performance Summary

ERROR QUANTITY	ERROR MAGNITUDES			
	Combined Mode		Beacon-only Mode	
	\bar{x} (nm)	$+1\sigma$ (nm)	\bar{x} (nm)	$+1\sigma$ (nm)
TSCT	.1561	.4044	.2680	.4231
FTE	-.0039	.6448	.5587	.6935
ASE	.1600	.6360	-.2908	.4218
ATE	.3587	.2816	.3955	.3071

Table 5.8 illustrates the behavior of both angular and linear errors for the RCA Primus-50 radar system within the five mile distance-to-go area. The table indicates that the linear TSCT and FTE quantities are relatively small at all range intervals. Typical linear combined mode TSCT values range in magnitude from .20 nm at 1 nm to .46 nm at

5 nm. The beacon-only mode TSCT linear values are slightly smaller (i.e. $\pm .09$ to $\pm .40$ nm). The FTE linear values for both modes of operation range in value from $\pm .23$ nm to $\pm .51$ nm. The angular quantities are somewhat large for both operational modes. The combined mode TSCT and FTE linear and angular quantities range in value from ± 5.3 degrees to ± 12.9 degrees while the beacon-only mode values are slightly smaller ($\pm 4.5^\circ$ to $\pm 8.6^\circ$). Outside of five nautical miles the results presented in Section 5.3.5 indicate virtually the same results obtained within five (5) miles.

Table 5.8 ARA Offshore RCA Primus-50 Linear and Angular Errors as a Function of Along Track Distance

DISTANCE TO BEACON	ONE SIGMA TSCT AND FTE ERROR QUANTITIES							
	Combined Mode				Beacon-only Mode			
	TSCT		FTE		TSCT		FTE	
	nm	Deg	nm	Deg	nm	Deg	nm	Deg
1 nm	$\pm .20$	± 11.4	$\pm .23$	± 12.9	$\pm .09$	± 4.9	$\pm .15$	± 8.6
3 nm	$\pm .45$	± 8.4	$\pm .48$	± 9.1	$\pm .44$	± 8.3	$\pm .42$	± 7.9
5 nm	$\pm .46$	± 5.3	$\pm .51$	± 5.8	$\pm .40$	± 4.5	$\pm .43$	± 4.9

The RCA Primus-50 radar system performed well during the flight test program. Operationally there is only one significant problem evident from the test results. In the combined mode, because of the large displayed beacon size, surface objects in the immediate area of the intended target are blocked out by the beacon return. This fact will be discussed in further detail in Section 5.1.3.

Data presented in Section 5.3 offers some very interesting conclusions. First, the track orientation techniques evaluated (cursor and multiple beacon) indicate a significant reduction in the overall TSCT and FTE values. Second, without some means of positive target identification in the skin paint mode navigation down to minimums could be dangerous. Third, if in the skin paint mode, the target is correctly identified then results indicate that this particular mode of operation is just as accurate as single beacon. Fourth, the combined mode of operation must provide a smaller beacon return so that surrounding surface objects can be displayed.

5.1.3 ATC Integration

An operational evaluation of the ARA concept in today's ATC environment was also performed. Section 5.4 discusses this analysis in detail for airport and offshore sites ATC procedures. A summary of this

analysis is presented in this section.

The net result of the operational evaluation of the ARA concept in the ATC environment was that it is a practical and viable solution to providing non-precision approach capabilities where other navigation aids are unavailable. This conclusion applies to both approach regions investigated. Although current ARA ground and airborne equipment performed acceptably during these tests, operational utilization in the day-to-day ATC environment would benefit from several ARA system enhancements. First, the ground based equipment could be improved in both signal strength and reliability. Second, more advanced radar features are highly desirable to reduce crew workload and improve the safety of the ARA concept. These improvements are in the areas of automatic gain control and tilt control, variable gain beacons and improved display characteristics. Third, formal crew training procedures and requirements must be developed. With these modifications, the ARA system can provide ATC compatible performance which exceeds the experimental performance at airports and offshore sites.

In the airport area, an ARA approach closely parallels the standard NDB non-precision approach technique in both workload and accuracy. In fact, the approach flown using the track orientation techniques more than satisfied the present day NDB airspace requirements. The experimental airport data (which included single beacon, beacon with cursor and multiple beacon approaches) showed lateral accuracy well within current landside lateral obstacle clearance minima. However, current ARA lateral obstacle clearance limits established by RTCA SC-133 MOPS exceed NDB and other non-precision approach values. Therefore, unless some type of track orientation technique is implemented, either using the cursor technique or multiple beacon technique, minimums higher than present day non-precision approaches might need to be implemented for ARA. Graphic illustrations are presented in Section 5.4 which demonstrate the behavior of ATE, ASE, TSCT and FTE with respect to specific limits. Basically, the ATE and ASE errors are independent of range from the target. On the other hand the single beacon TSCT and FTE errors exhibit the "homing" characteristics previously discussed while the beacon with cursor and multiple beacon TSCT and FTE errors

do not. From an ATC integration viewpoint, higher altitudes and larger lateral obstacle clearance minimums require more airspace. This could limit the areas where ARA would be usable or it could necessitate special approach procedures, such as the point-in-space approaches, to congested terminal areas where adequate approach airspace is not available to the active runway. Airport ARA approaches also require positive navigation when flying to the Initial Approach Fix. This could translate into a requirement for beacons on the ground or some additional airborne navigation equipment (such as the RNAV system used for these tests). Even with these additional navigation aids, multidirectional ARA procedures at airports will require careful planning and a high degree of pilot proficiency to achieve the desired accuracy.

In the offshore ARA tests, three operational ATC considerations are important. First, the ARA system and procedures must provide accurate and repeatable guidance to an IAF in the vicinity of the offshore target. Second, the ARA system must provide adequate guidance in a controlled descent to the specified minimums while providing adequate obstacle clearance. Third, the ARA procedures must provide a simple and safe missed approach procedure in the vicinity of a multitude of prominent surface objects. While the first condition was satisfied during the offshore testing the second and third conditions were not for two reasons. First, during the skin paint testing on two occasions the wrong target was tracked down to minimums. This indicates that without positive target identification, obstacle clearance and safe missed approach procedures cannot be assured. Second, because of the large beacon displayed in the combined mode, obstacle clearance in the immediate area of the intended target cannot be assured. Results presented in Section 5.4 indicate that on the 2.0 nm range selector setting a circle approximately 840 feet in radius is blocked out around the intended target by the large displayed return. Offshore the ARA system is a viable means of accurate navigation but because of the above mentioned items certain important problems must be corrected in certain operational modes before safe navigation can be conducted in a real environment.

5.2 ANALYSIS OF PILOT PROCEDURES

Pilot ARA procedures were developed which resulted in safe approaches with acceptable cockpit workload. These procedures were compatible with current ATC operational constraints in the airport and offshore areas. The pilots experienced a learning curve effect due to the previous single beacon approach testing conducted at the airport, remote and offshore sites (Reference 1). The profiles and procedures utilized during the track orientation testing were virtually identical to those utilized during previous testing. The conceptual aspects of the flight test included utilizing one of two basic flight profiles to perform the approach. These were the direct straight and overhead straight profiles. The use of these flight profiles provided approach procedures that were adaptable to existing meteorological conditions at the landing site.

The empirical aspects of the ARA approach procedures were in the area of pilot/copilot responsibility assignments. It was determined during the single beacon testing that the following ARA crew workload assignments were found acceptable:

- The pilot was given primary responsibility for flight control and safety of flight.
- The pilot was assigned radio communications duties.
- The copilot was solely in charge of ARA navigation.
- The copilot was responsible for interpreting the radar (cursor track angle error and multiple beacon orientation) and communicating required headings, heading changes, altitudes and airspeeds to the pilot.

The crew coordination procedures combined with the flight profile procedures resulted in a calm and coordinated cockpit environment. These procedures also insured maximum obstruction clearance while meeting the required test objectives. In summary, the flight procedures were simple, offered a considerable amount of versatility and integrated well with the operational ATC System.

5.2.1 Pilot/Copilot Workload

The pilot/copilot workload involved in flying an Airborne Radar Approach is quite heavy. Based on qualitative observations experienced during the single beacon testing, the Airborne Radar Approach was concluded

definitely to be a two pilot operation. The Airborne Radar System is a good approach aid, but for the pilot to interpret the given information, and to constantly adjust the radar display controls, requires considerably more effort than any other standard non-precision approach using conventional radio navigation aids. For this reason two track orientation techniques were conceived; single beacon and skin paint with cursor, and the multiple beacon technique. It was the intent of the test program to evaluate whether either of these track orientation techniques alleviated workload and improved track keeping. Probably the greatest workload aspect of the airborne radar tested were the constant adjustment required of the gain, tilt, and radar range controls. Gain adjustment was a problem during the multiple beacon testing because the Sensitivity Time Constant (STC) adjustment for this particular radar unit was not set properly. The radar was adjusted and operated adequately during the track orientation technique testing. There were, however, optimum tilt settings that were found to apply during the approaches, e.g., -2 degrees was found to be the optimum setting. Although the -2 degrees tilt setting worked for the entire approach, a constant tilt setting was not necessarily the best recommended procedure for flying the approach. Theoretically the tilt should be adjusted so that the target is scanned within the radar's vertical beam width.

The copilot's workload consisted primarily of three distinct items:

- Radar target interpretation in relation to intended course (radar interpretation included track orientation utilizing the cursor and multiple beacon techniques).
- Operation of radar display controls.
- Range and heading call-outs to the pilot.

Aside from the track orientation techniques utilized, the radar target interpretation is strictly empirical for many reasons. First, on the Bendix Radar System with the STAB indicator on the 120 degree setting, there are only azimuth lines every 30 degrees displayed on the radar screen in the BCN mode. However, in the SCH modes azimuth lines are displayed every 15 degrees. Therefore, if the target lies between the azimuth lines the copilot must be able to interpret his position relative to zero azimuth accurately. On the Primus-50 radar if the azimuth button is activated, azimuth lines are generated every 15 degrees on the radar

screen. Azimuth lines every 15 degrees reduces azimuth interpretation errors, but in the case of the Primus-50 radar system because of the large "blob" that is displayed as the beacon return, azimuth interpretation is again difficult. This large return also makes range interpretation extremely difficult. A more detailed description of the Primus-50 target size will be presented in Section 5.4. Second, the copilot must assume (regardless of the radar system) that the center of the beacon return displayed on the screen is the intended target. In the case of the Primus-50 radar return it must be assumed that the center of the edge closest to the apex is the intended target. The target width analysis presented in Section 5.0 of Reference 1 for the Bendix Radar System showed a mean value of 13.18 degrees and a one-sigma of 4.10 degrees. It is apparent that this large target width or target size would put a limitation on the pilot's interpretive judgement of actual position with relation to the intended course. Another cause for error in display interpretation is the slow update rate of the airborne radar. Five seconds is required for the Bendix system to sweep in one direction. Therefore, aircraft heading could change considerably while the displayed target appears to stay stationary. All of the above factors greatly increase the workload of the copilot, making his position as navigator a full time job.

In the skin paint mode target identification poses a distinct problem for the copilot. Because of numerous targets surrounding the intended target, positive target identification from twenty-five (25) nautical miles was virtually impossible and within ten (10) nautical miles was marginally acceptable. During the skin paint testing correct target identification was a "best guess" situation. Section 5.3.1 shows that on two occasions the copilot identified the wrong target and flew the approach either to a ship or a different lighthouse. On another occasion the copilot tracked the wrong target at the beginning of the approach, but then later identified the correct one and completed the approach. The lack of positive target identification and numerous surrounding targets in the landing area causes a large increase in workload for the copilot in the skin paint mode.

The combined mode which was tested using the RCA Primus-50 offers the ability to receive a ground based transponder and surrounding skin paint targets simultaneously. This mode offers positive target identification

while at the same time affording the pilot obstacle clearance; but because of the large displayed beacon size on the Primus Radar targets, immediately surrounding the beacon are not visible. In the combined mode the beacon target is easily discernable from other targets because it flashes on and off at one second intervals. Again, all of the above factors tend to increase the copilot's mental workload.

The purpose of the cursor and multiple beacon techniques were to aid the copilot in track orientation and to also alleviate the copilot's mental workload. With the cursor technique it was only necessary for the copilot to align the cursor with the center of the return. When this was accomplished the aircraft was on course with the correct amount of drift angle already implemented. The copilot's general reaction during the testing was that the cursor definitely aided in track orientation and that it also reduced the amount of mental workload involved. The multiple beacon testing offered different results as regards workload. Although the multiple beacon technique improved track orientation because of the two targets displayed, the mental workload was greater because the track angle error was not displayed directly on the screen. It was the copilot's responsibility to form an image of the "intended course line" between the targets.

Three other problems were also experienced during the multiple beacon testing. First, because the STC circuit was improperly adjusted on the Bendix Radar System it was necessary to constantly adjust the gain control. Even with constant adjustment, at large longitudinal spacings the beacon for which the gain was not adjusted either disappeared or was splayed across the entire azimuth of the screen. In either case the target was not useable for navigation. Second, at times one of the two ground based beacons was found to be inoperative. This caused a great deal of confusion for the copilot because without discrete positive identification for each particular beacon it was impossible to determine which beacon was the observed target. Third, when tracking the two beacons inbound a range scale change often resulted in the second beacon being beyond the screen display. When the second beacon was lost, obviously track orientation information was not available to the copilot. It is apparent that the multiple beacon testing induced a certain level of mental workload not previously encountered during other areas of testing.

The pilot's workload was quite different from that of the copilot. It was the pilot's sole responsibility to fly the aircraft and handle all Air Traffic Control (ATC) communications. As mentioned earlier the pilot was unhooded throughout the entire flight test. This was done for a particular reason: along with his other responsibilities the pilot needed to be aware and look out for all other traffic in the area. The observer and crew chief onboard the helicopter also aided in watching for traffic, but it was the major responsibility of the pilot to do so. Since the traffic around the NAFEC airport was fairly dense, many times there was a considerable amount of confusion in the pilot/copilot and pilot/ATC communications. Often times this delay in communications from the copilot to the pilot resulted in a deviation from intended course or a delayed correction to reacquire the intended course. Another pilot workload factor introduced during the flight occurred on the final approach course. Because of the slow airspeed (50 knots), handling of the helicopter became a problem particularly in crosswind conditions.

Pilot and copilot workload rating sheets were given to each crew member at the end of every flight. The pilots rated themselves on the level of mental and physical effort applied in flying each Airborne Radar Approach. The copilots rated themselves on the level of mental and physical effort applied in navigating and vectoring each Airborne Radar Approach. Table 5.9 summarizes the responses which the pilot and copilot indicated on the workload rating sheets for all of the different flight test areas. The table shows that at no time during the testing did the pilot or copilot consider the workload to be low or very low. It is evident from Table 5.9 that the pilots considered the beacon with cursor approaches to have only a moderate workload, while during the single beacon testing the pilots considered the workload to be either high or very high on nine of the twenty flights. The single beacon approach testing shows slightly higher workload rating because during this phase of testing learning curve effects were still being encountered. Table 5.9 shows that in multiple beacon testing five of the flights were considered to be of moderate workload and three of the flights were considered to be a high workload situation. During the skin paint and skin paint with cursor testing all of the flights were considered to be

Table 5.9 Pilot/Copilot Workload Ratings

Workload Rating	NUMBER OF FLIGHTS											
	Single Beacon*		Beacon W/Cursor		Multiple Beacon		Skin Paint		Skin Paint W/Cursor		Primus-50 Testing	
	Pilot	Copilot	Pilot	Copilot	Pilot	Copilot	Pilot	Copilot	Pilot	Copilot	Pilot	Copilot
Very Low	0	0	0	0	0	0	0	0	0	0	0	0
Low	0	0	0	0	0	0	0	0	0	0	0	0
Moderate	7	4	4	4	3	2	3	3	3	2	4	3
High	3	5	0	0	1	2	0	0	0	1	1	0
Very High	0	1	0	0	0	0	0	0	0	0	0	2

* See Reference 1 (Section 6.1) for details.

of moderate workload with one exception. During the Primus-50 testing seven of the flights were considered to be of moderate workload and three of the flights were considered to be either a high or very high workload situation. Basically the pilots consider the Airborne Radar Approach to be either a moderate or high workload situation, with the track orientation techniques tending to decrease the level of mental workload involved. This fact is evident from Table 5.9.

5.2.2 Pilot/Copilot Blunders

The pilot/copilot blunders encountered during the test were few. One type of blunder encountered was the improper adjustment of display controls. The display control problems encountered were as follows: the scale being changed too soon leaving no target on the radar screen, improper gain adjustment often making the target disappear, and improper adjustment of the tilt control, making close-in navigation difficult. Basically the only other blunders experienced were during the skin paint testing. On two occasions the wrong target was identified and tracked down to approach minimums. On the first instance a lighthouse was tracked and on the second instance a ship was tracked. On the third occasion a ship was tracked in the beginning of the approach until positive target identification was made (for details see Section 5.3.1 and 5.3.2). The following section will describe in detail the accuracy data accumulated during the flight test program. The data is presented so that the reader can make a detailed comparison between various operational modes.

5.3 DETAILED ACCURACY DATA

The purpose of this subsection is to provide insight into the flight test results and data analysis for the Airborne Radar Approach flight test program. The areas of interest involved the RCA Primus-50 and the Bendix RDR-1400A Airborne Radar Systems. The details presented in this subsection represent the results of a comprehensive review of the specific data collected during the Airborne Radar Approach flight test program using new track orientation techniques. The approach data collected involving new track orientation techniques will be compared with the appropriate areas where track orientation techniques were not utilized (Reference 1). The data is presented in four different forms. They are as follows:

- Statistical summary tables showing mean and standard deviation of four error quantities.
- Statistical summaries of data aggregated at one nautical mile intervals along the approach path.
- Plots of Total System Cross Track (TSCT), Flight Technical Error (FTE), and Airborne System Error (ASE), versus along track position of the helicopter.
- Histograms of TSCT, FTE, ASE and Along Track Error (ATE) quantities for each test area.

5.3.1 Offshore Site: Beacon-only and Skin Paint Comparison

This subsection provides a direct comparison between the Bendix RDR-1400A beacon-only and skin paint mode testing conducted at the offshore site. The test environment and approach profiles utilized remained the same offering a means by which a direct comparison could be made.

Table 5.10 summarizes the results of the Airborne Radar Approach testing conducted in the skin paint mode*. The error analysis log and statistical summary of error quantities in the table presents the mean values, standard deviations, number of data points and number of approach segments for four specific error quantities: ARA along track (ATE), ARA cross track (ASE), flight technical error (FTE), and total system cross track (TSCT).

Table 5.10 shows in the ARA ATE case that the calculated mean is .0345 nm and the sigma is .2567 nm for all of the approach segments. The results for the ARA ASE were a total mean value of .1955 nm, and a one-sigma value of .6264 nm. The values were obtained from a sample size of 466 data points or seven (7) approach segments.

Table 5.11 summarizes the results of the Airborne Radar Approach testing conducted at the offshore site in the single beacon mode. The data is presented in the same general format as the data in Table 5.10. The data for this table was collected during the period from October 1978 to December 1978 (see Reference 1 for details). The data was originally aggregated using three different types of approach segments: long, short

*Note: Two approaches were flown to the wrong target. These were not included in the data summaries.

Table 5.10 NAFEC ARA Bendix RDR-1400A Skin Paint
Offshore Approaches Error Analysis Log
And Statistical Summary

<u>ARA ATE</u>	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
Long	.0706	.0965	116	1
Short	.0225	.2901	350	6
Total	.0345	.2567	466	7
<u>ARA ASE</u>				
Long	.8343	.7792	116	1
Short	-.0163	.3770	350	6
Total	.1955	.6264	466	7
<u>FTE</u>				
Long	-.4260	.7959	116	1
Short	.2230	.4726	350	6
Total	.0615	.6350	466	7
<u>TSCT</u>				
Long	.4083	.4084	116	1
Short	.2068	.2982	350	6
Total	.2570	.3400	466	7
<u>IDENTIFIER</u>	<u>True Heading</u>		<u>Segment</u>	
7/16/79 -2	222		Short	
7/16/79 -3	222		Short	
7/17/79 AM-2	222		Short	
7/17/79 AM-3	222		Short	
7/17/79 PM-1	222		Long	
7/17/79 PM-2	222		Short	
7/17/79 PM-3	222		Short	

Table 5.11 NAFEC ARA Bendix RDR-1400A Beacon Mode
Offshore Approaches Error Analysis Log
And Statistical Summary

<u>ARA ATE</u>	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
Long	.0052	.2502	978	9
Short	-.0115	.1014	123	3
Total	.0033	.2383	1101	12
<u>ARA ASE</u>				
Long	-.2235	.5588	978	9
Short	-.0315	.2235	123	3
Total	-.2021	.5353	1101	12
<u>FTE</u>				
Long	-.0844	1.0456	978	9
Short	.4269	.6026	123	3
Total	-.0273	1.0185	1101	12
<u>TSCT</u>				
Long	-.3079	.8938	978	9
Short	.3954	.5081	123	3
Total	-.2293	.8873	1101	12
<u>IDENTIFIER</u>	<u>True Heading</u>		<u>Segment</u>	
11/14/78 -3 Initial	150		Long	
11/15/78 -1	222		Long	
11/15/78 -2	222		Long	
12/12/78 -3	150		Long	
12/12/78 -4 Initial	150		Long	
12/12/78 -4 Final	330		Short	
12/13/78 AM-1 Initial	222		Long	
12/13/78 AM-1 Final	42		Short	
12/13/78 AM-2 Initial	222		Long	
12/13/78 AM-2 Final	42		Short	
12/13/78 AM-3 Initial	150		Long	
12/14/78 -1	222		Long	

and offset, but for purposes of comparison the data was recomputed to reflect only the long and short segments. Table 5.11 shows in the ARA ATE statistics that the total mean value is .0033 nm and the one-sigma value is .2383. The ARA ASE results show a mean value of -.2021 nm and a one-sigma of .5353. The ARA ATE results presented in Table 5.10, show a mean value of .1955 nm and a one-sigma of .6264 nm. In the beacon mode the ARA ATE mean is virtually zero, with the same holding true for the skin paint mode. These data in Table 5.11 were calculated from a sample size of 1101 data points or twelve (12) approach segments.

The Flight Technical Error (FTE) quantities indicated in Table 5.10 showed a mean value of .0615 and a one-sigma of .6350. The FTE values indicated in Table 5.11 for the beacon mode show a smaller mean value of -.0273 nm, with the one-sigma being slightly larger 1.0185 nm for all segments. The larger mean could be attributed to the lack of positive identification available in the skin paint mode as opposed to the beacon mode. This lack of positive identification makes target tracking difficult, with a large increase in pilot workload. The Total System Cross Track (TSCT) values indicated in Table 5.10 for the skin paint mode shows a mean value of .2570 nm and a one-sigma of .3400 nm. Table 5.11 shows a TSCT total mean of -.2293 and a one-sigma of .8873. While the skin paint mean is slightly larger and of a different sign than the beacon mode results, the TSCT one-sigma is smaller in the skin paint mode.

Tables 5.10 and 5.11 indicated that the approaches were aggregated according to two segment types: long and short. The long segments are generally approaches initiated at the 25 nm approach fix. The short segments are generally of two types, at the offshore site they are those approaches initiated at 10 nm while at the airport site they begin at 5 nm.

Tables 5.12 and 5.13 summarizes in statistical quantities the Airborne Radar Approach test data at one nautical mile intervals, starting at ten (10) nautical miles*. The quantities in Table 5.12 reflect data collected in the skin paint mode and the data in Table 5.13 was obtained in the offshore single beacon mode testing (Reference 1). The quantities in both tables were calculated in both linear and angular terms, for both long and short segments. In Table 5.12 at one nautical mile

NOTE/*In these tables and similar ones to follow, a single data point was taken from each approach at one nautical mile increments.

Table 5.12 Bendix RDR-1400A Skin Paint Mode One Nautical Mile Aggregate Data

NM	STD	LINEAR ERRORS					ANGULAR ERRORS				
		AVE	TSET	FFD	RSE	TSET	FFE	TSET	FFE	ASE	MEAN
1		.0250	.0114	.1003	.1117	.0530	5.7260	6.3717	5.7260	6.3717	MEAN
		.0031	.1932	.0001	.0001	10.3025	14.0115	5.3155	5.3155	5.3155	STD
		.0000	.1177	.0111	.0001	3.0735	6.0376	2.1643	2.1643	2.1643	MEAN
		.0000	.0860	.0001	.1243	3.5580	11.5423	3.6126	3.6126	3.6126	STD
		.0001	.1713	.0001	.0001	6.0381	7.5623	-1.0130	-1.0130	-1.0130	MEAN
		.4012	.6142	.4827	.1143	7.8621	9.1410	2.1821	2.1821	2.1821	STD
4		.1011	.0001	.0001	.1053	5.7017	4.2043	1.5074	1.5074	1.5074	MEAN
		.0607	.6401	.4001	.3326	6.2757	6.6201	4.7521	4.7521	4.7521	STD
		.1001	.1001	.0001	.4941	4.6665	-1.9031	5.2474	5.2474	5.2474	MEAN
		.0001	.0001	.0001	.6151	4.5480	9.1413	7.6179	7.6179	7.6179	STD
		.1001	.0001	.0001	.0001	1.6123	-1.1501	3.7670	3.7670	3.7670	MEAN
		.1076	.0001	.0001	.7542	2.3537	5.0260	7.1640	7.1640	7.1640	STD
		.1156	.0001	.2471	.1117	2.9341	2.0241	.9115	.9115	.9115	MEAN
		.1000	.0001	.0001	.6008	2.7180	3.9648	5.6358	5.6358	5.6358	STD
		.1011	.0001	.0001	.2083	1.9810	.3437	1.6382	1.6382	1.6382	MEAN
		.0701	.0001	.0001	.7268	2.0658	4.5321	5.2224	5.2224	5.2224	STD
		.1001	.0001	.0001	.2052	1.9207	.5001	1.3250	1.3250	1.3250	MEAN
		.0001	.0001	.0001	.0001	1.7160	4.7401	5.7423	5.7423	5.7423	STD
		.0001	.0001	.0001	.0001	2.1610	-1.9449	3.1051	3.1051	3.1051	MEAN
12		.0001	.0001	.0001	.0001	.4112	1.6141	3.2060	3.2060	3.2060	STD

UNRELIABLE

Table 5.13 Bendix RDR-1400A Offshore Site Beacon Mode One Nautical Mile Aggregate Data

[illegible]

PROPERTY DISPOSABLE

the skin paint FTE mean is 5.7 degrees and the one-sigma is 14.0 degrees. The beacon mode FTE in Table 5.13 at one nautical mile shows a slightly smaller mean of -1.2 degrees while the one-sigma is virtually identical, 14.5 degrees in the beacon mode. Other FTE quantities between one and four nautical miles reflect the same orders of magnitudes as numbers previously stated. The skin paint TSCT quantities in Table 5.12 show a mean angular value of -.65 degrees and a one-sigma of 10.4 degrees at one nautical mile. The offshore single beacon TSCT quantities in Table 5.13 show a mean angular quantity of -2.4 degrees and a one-sigma of 16.5 degrees at one nautical mile. The skin paint linear TSCT mean at one nautical mile is -.01 nm and the one-sigma is .18 nm. The skin paint linear TSCT mean quantities past 3 nm stay consistently the same (i.e., between .3 and .4 nm). The linear FTE quantities in the skin paint mode are good close in (between 1 and 2 nautical miles) but further out at 3 and 4 nautical miles the mean quantities are .40 and .30 nm respectively. The skin paint ATE quantities are small and consistent at all ranges of operation. The ARA Airborne System Errors (ASE) in the skin paint mode reflect linear quantities that are larger than the beacon mode quantities at most ranges. For example, at ten (10) nautical miles Table 5.12 shows a mean value of .54 nm while Table 5.13 shows a mean of -.26 nm. These larger quantities in the skin paint mode are likely attributable to the numerous targets present on the radar screen causing many targets to run together. This overlap of target display tends to cause confusion on the part of the operator, making track orientation difficult to obtain. This confusion on the part of the operator in the skin paint mode also lends itself to larger FTE quantities. For example, as shown earlier in the skin paint mode at 3 and 4 nautical miles the mean values were .40 and .30 nm respectively while in the beacon mode at 3 and 4 nautical miles the mean values are .07 and -.08 nm, respectively.

Figure 5.1 summarizes in graphical form the Total System Cross Track Error (TSCT) of all the approaches* flown at the offshore site in

/NOTE/*All of the TSCT, FTE and ASE aggregate plots supplied in Section 5.3 reflect the total number of approach segments flown. For example, the overhead straight approach contains two separate approach segments.

ARA APPROACHES -- OFFSHORE SITE
BENDIX RDR-1400A SKIN PAINT MODE

9 APPROACHES
AGGREGATE TSOT

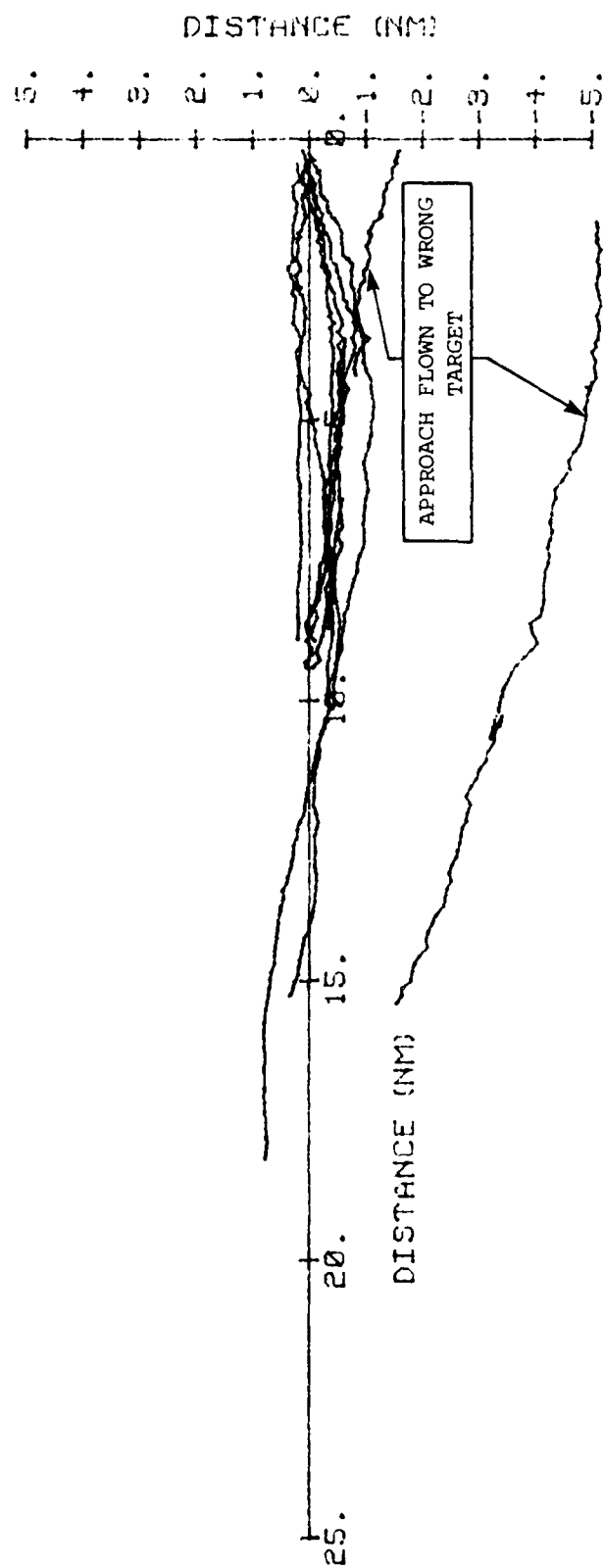


Figure 5.1 ARA Offshore Skin Paint Mode Approach Total System Cross Track Error

the skin paint mode. The plot shows that when the target was positively identified the maximum deviation from intended course was only ± 1.2 nm within five nautical miles. This quantity is well within the required airspace limits of ± 1.7 nm at the Missed Approach Point (MAP) set by the RTCA SC-133 MOPS. Outside of five nautical miles the maximum deviation from intended course was $\pm .7$ nm which is well within the ± 4 nm airspace requirements established by RTCA SC-133 MOPS. Figure 5.1 also shows that on two occasions the target was not identified properly and placed the aircraft -1.7 and -5.0 nm off-course at the MAP. Figures 5.2 and 5.3 are individual plots of the above mentioned approaches which reflect TSCT and FTE for each approach.

Figure 5.4 summarizes as in Figure 5.1 the Total System Cross Track Error (TSCT) of all the long and short approaches flown at the offshore site in the beacon mode. Although in some cases the maximum deviation from intended course is greater outside of five nautical miles than those seen in the skin paint mode, within five nautical miles all of the approaches were flown directly to the target because of positive identification. This concept of positive target identification is very important in a real environment where many oil rigs are situated in a cluster with ships moving all about.

Figure 5.5 is a plot of Flight Technical Error (FTE) vs. distance along the desired track in the skin paint mode. These data were collected for all of the approaches flown at the offshore site. These data show a maximum deviation of 4.5 nm at 17.5 nm along the desired track and also a maximum deviation of 2.4 nm at 2.5 nm. These large FTE quantities can be attributed to the pilot not identifying the target correctly and flying to something other than the intended target (a ship and another lighthouse). This misidentification comes about because of numerous targets displayed on the radar screen due to heavy ship activity surrounding the intended target. Figure 5.6 presents a plot of FTE vs. along track distance for the single beacon approach testing. With the exception of one approach, which was flown on the wrong approach course, at most ranges the majority of the FTE quantities remain within an area of ± 2.5 nm.

Figure 5.7 is a plot of Airborne System Error (ASE) for the approaches flown at the offshore site in the skin paint mode. Outside of ten (10) nautical miles Figure 5.7 shows a maximum Airborne System Error (ASE)

AD-A088 426

SYSTEMS CONTROL INC (VT) PALO ALTO CA

F/G 17/7

AIRBORNE RADAR APPROACH FLIGHT TEST EVALUATING VARIOUS TRACK OR--ETC(U)

JUN 80 L D KING

DOT-FA79WA-4293

UNCLASSIFIED

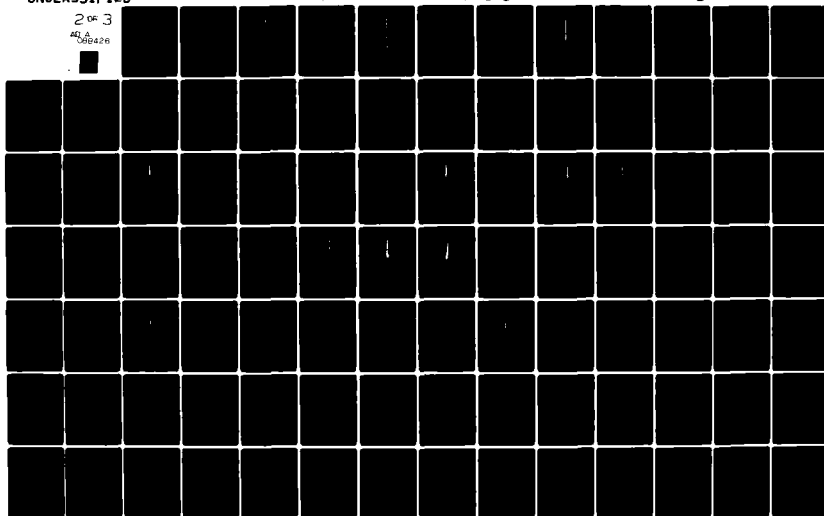
FAA-RD-80-60

NL

2 OF 3

AD-A088 426

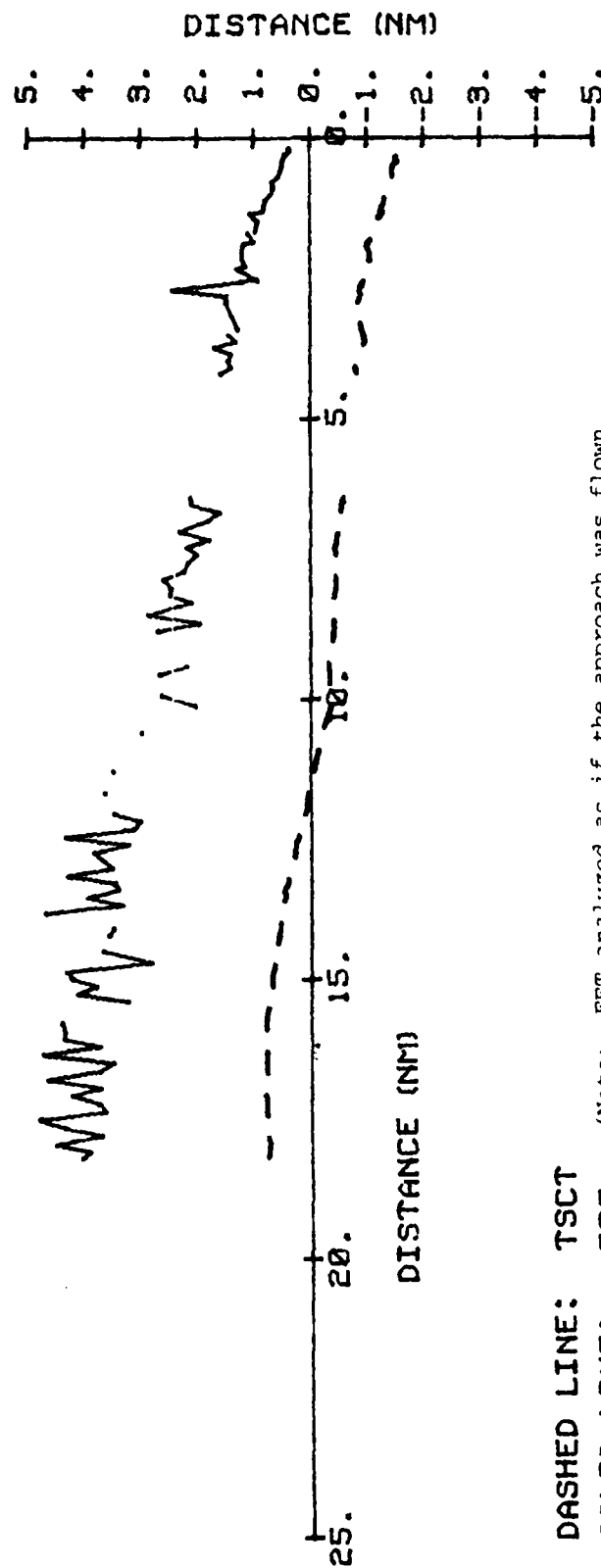
■



ARA APPROACH -- OFFSHORE SITE
BENDIX RDR-1400A SKIN PAINT MODE

00717A1

FLIGHT DATE: 7/17/79-1 AM
STRAIGHT IN -- 222 DEG. TN



DASHED LINE: TSCT
SOLID LINE: FTE

(Note: FET analyzed as if the approach was flown to the correct target.)

(NOTE: Approach Flown To The Wrong Target)

Figure 5.2 ARA Offshore Site TSCT And FTE Plot: Direct Straight Approach Flown
17 July 1979

ARA APPROACH -- OFFSHORE SITE
BENDIX RDR-1400A SKIN PAINT MODE

007161

FLIGHT DATE: 7/16/79 - 1
STRAIGHT IN -- 222 DEG. TN

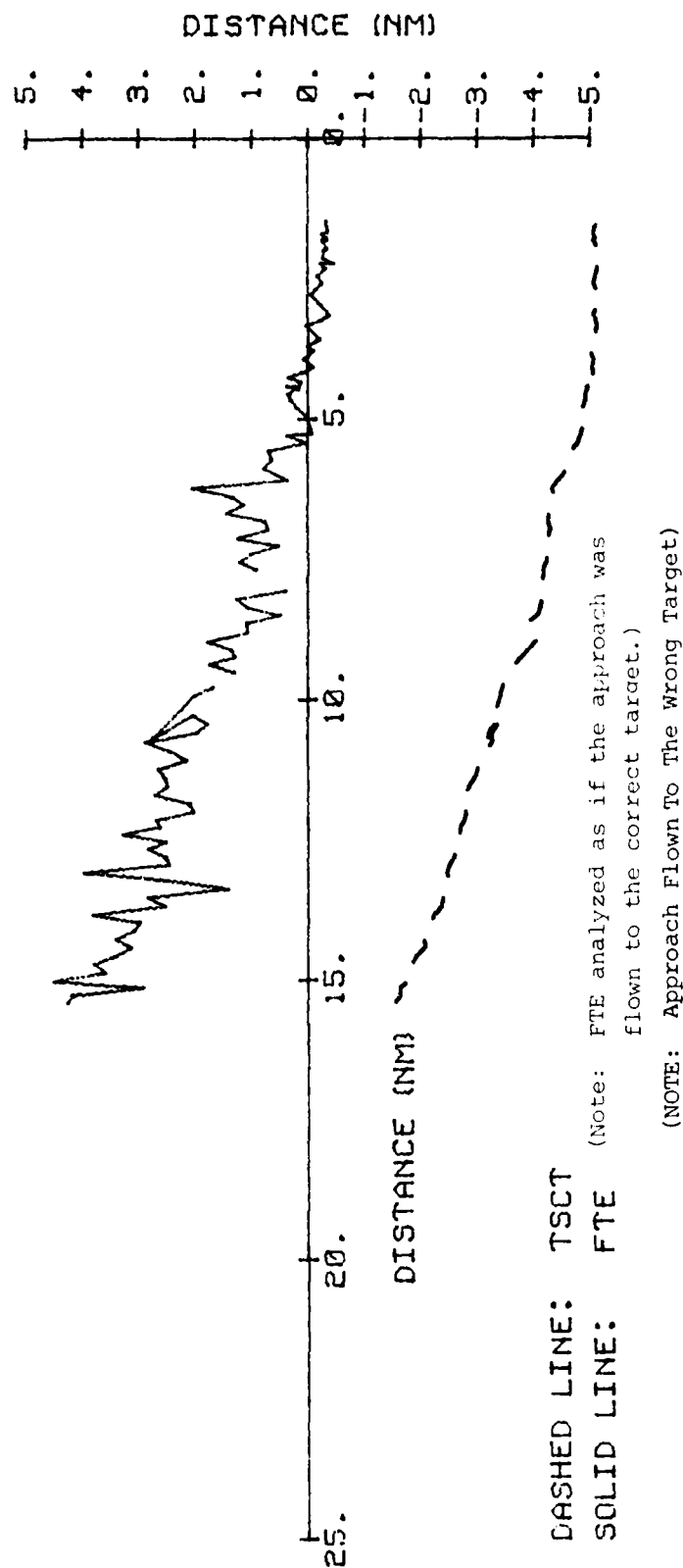


Figure 5.3 ARA Offshore Site TSCT And FTE Plot: Direct Straight Approach Flown
16 July 1979

ARA APPROACHES -- OFFSHORE SITE
BENDIX RDR-1400A SINGLE BEACON MODE

12 APPROACHES
AGGREGATE TSCT

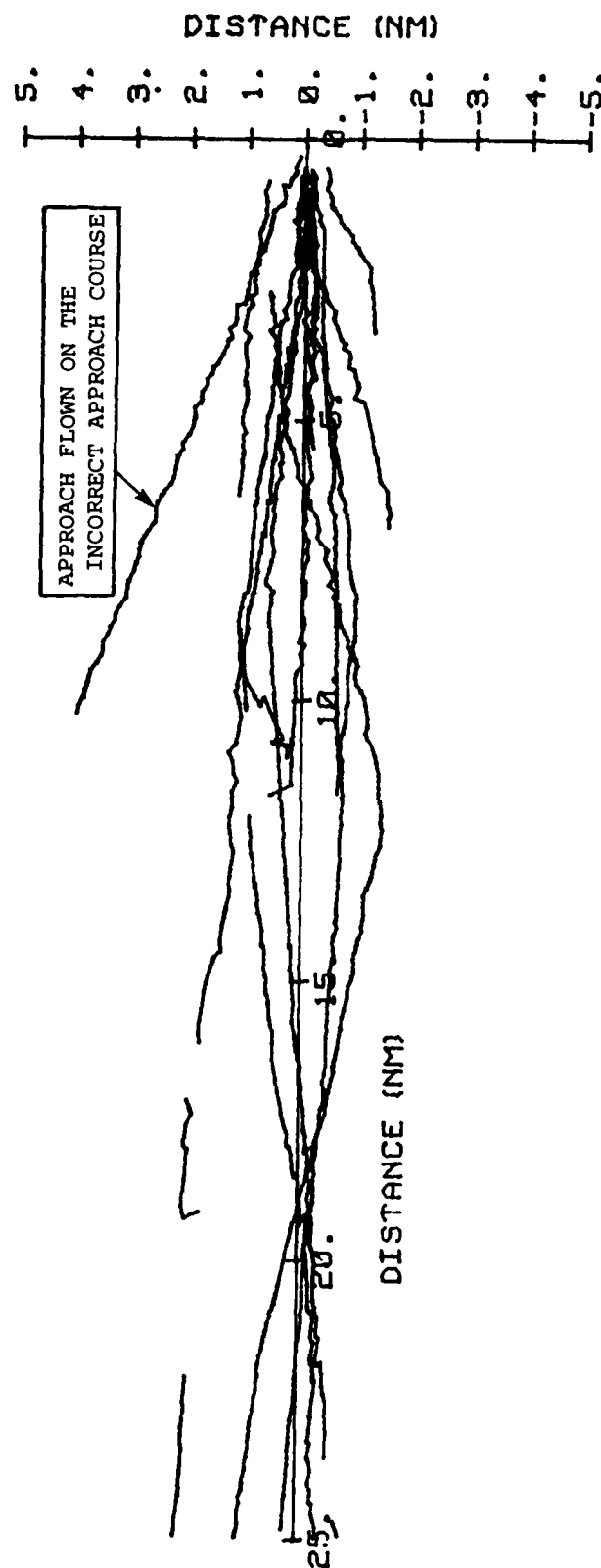
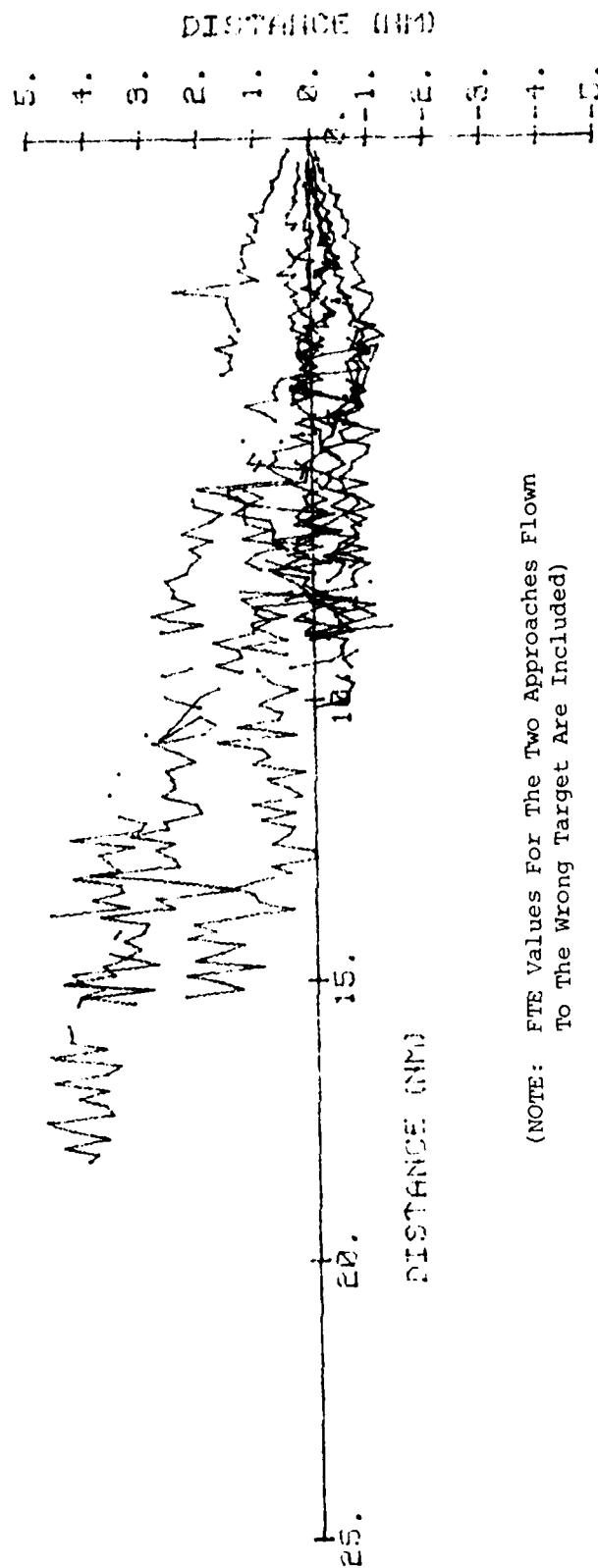


Figure 5.4 ARA Offshore Single Beacon Approach Total System Cross Track Error

ARA APPROACHES --- OFFSHORE SITE
 BENDIX RDE-1400A SKIN PAINT MODE

3 APPROACHES
 AGGREGATE FTE



(NOTE: FTE Values For The Two Approaches Flown
 To The Wrong Target Are Included)

Figure 5.5 ARA Offshore Skin Paint Mode Flight Technical Error

ARA APPROACHES -- OFFSHORE SITE
 BENDIX RDR-1400A SINGLE BEACON MODE

12 APPROACHES
 AGGREGATE FTE

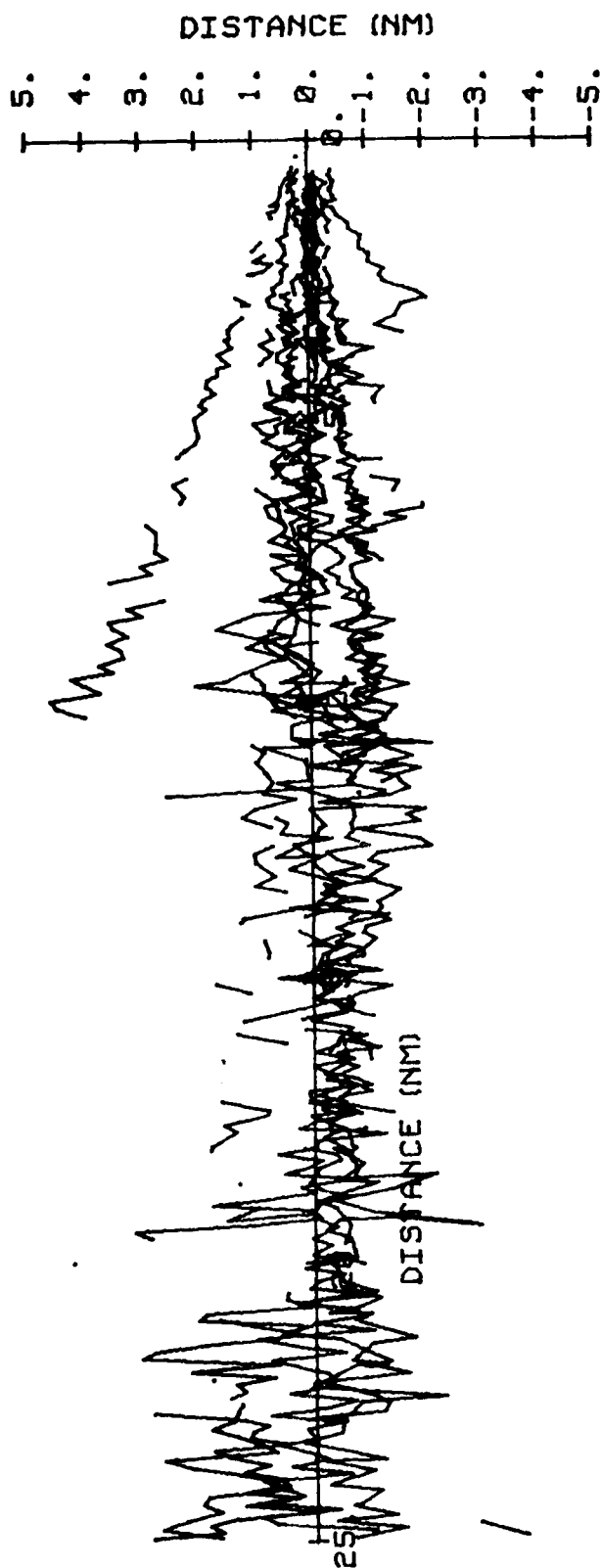


Figure 5.6 ARA Offshore Single Beacon Mode Flight Technical Error

ARA APPROACHES -- OFFSHORE SITE
BENDIX RDR-1400A SKIN PAINT MODE

9 APPROACHES
AGGREGATE ASE

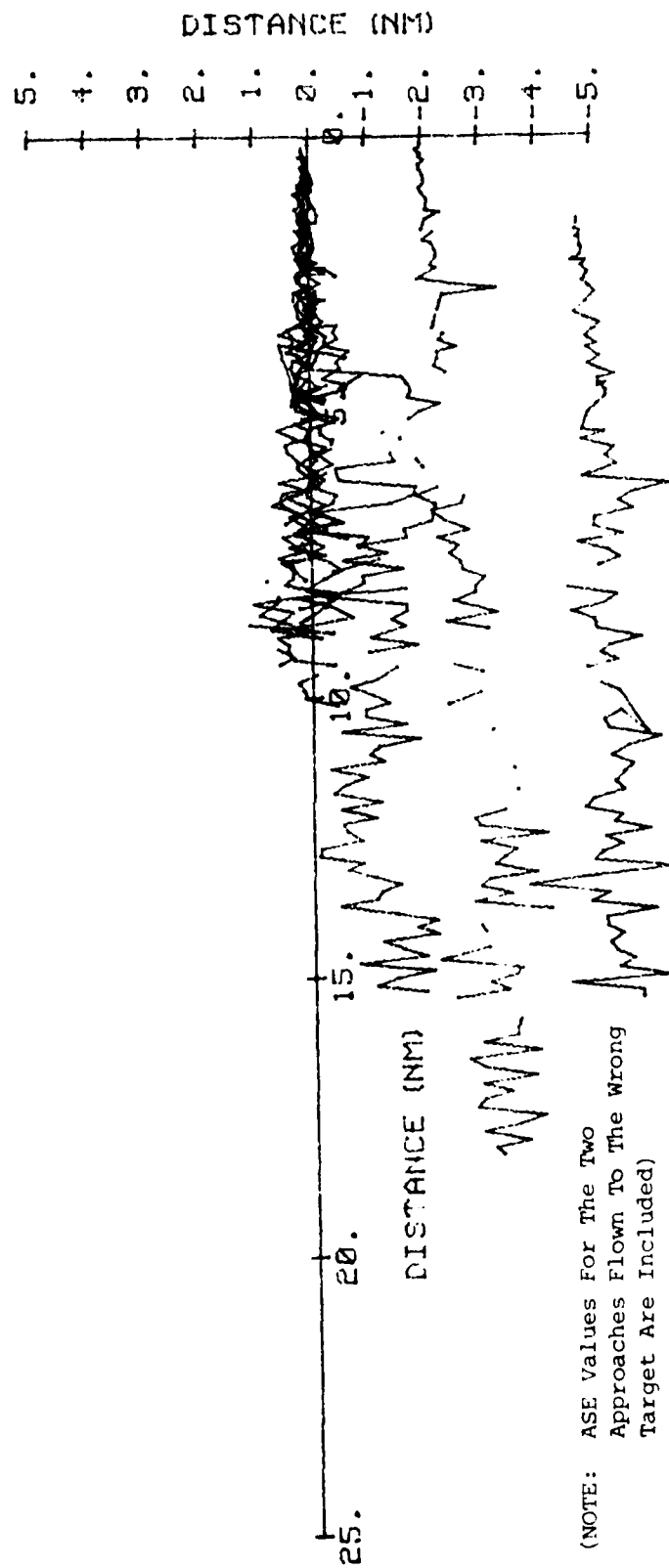


Figure 5.7 ARA Offshore Skin Paint Mode Airborne System Error

of -6.6 nm. Between ten (10) and five (5) nautical miles the plot indicates a maximum error of -6.5 nm. Within five (5) nautical miles the plot shows a maximum error of -5.5 nm. All of these large error quantities can be attributed to the approach where the pilot tracked the wrong target (another lighthouse) down to the MAP. Figure 5.8 is a plot of ASE for the single beacon mode. Quantities indicated between ten (10) and five (5) nautical miles show a maximum error of 1.8 nm. Within five (5) nautical miles the plot indicates a maximum error of only 1.0 nm.

Figure 5.9 presents histograms of ARA TSCT, FTE, ASE and ATE for the offshore skin paint mode testing. These histograms represent the error quantity distributions for the four error quantities mentioned previously. The TSCT histogram shows that the quantities appear skewed to the left. The FTE histogram shows the quantities appear to be skewed slightly to the right. The ATE quantities appear skewed to the left, while the ASE distributions appear skewed to the left.

Figure 5.10 presents histograms of ARA TSCT, FTE, ASE and ATE for the offshore single beacon mode testing. The TSCT histogram shows a normal distribution between ± 1.6 nm cross track deviation, but the histogram also indicates a very scattered distribution to -4.0 nm. The FTE distribution basically indicates the same characteristics as the TSCT distribution. The ATE quantities appear skewed slightly to the left, while the ASE quantities also appear skewed slightly to the left.

5.3.2 Offshore Site: Performance Enhancement In The Skin Paint Mode Using The Cursor Technique

This subsection will provide the detailed data necessary to establish an increase in the track keeping abilities of the radar operator using the cursor technique in the skin paint mode. The purpose of the cursor technique was to improve track acquisition and track orientation so that the operator could fly along a predetermined path instead of "homing" to the station. This subsection will show a definite decrease in the TSCT and FTE error quantities on the cursor-aided approaches.

Table 5.14 summarizes the results of the ARA testing conducted in the skin paint with cursor mode. The statistical summary of error quantities in the table presents the mean values, standard deviations,

ARA APPROACHES -- OFFSHORE SITE
 BENDIX RDR-1400A SINGLE BEACON MODE

12 APPROACHES
 AGGREGATE ASE

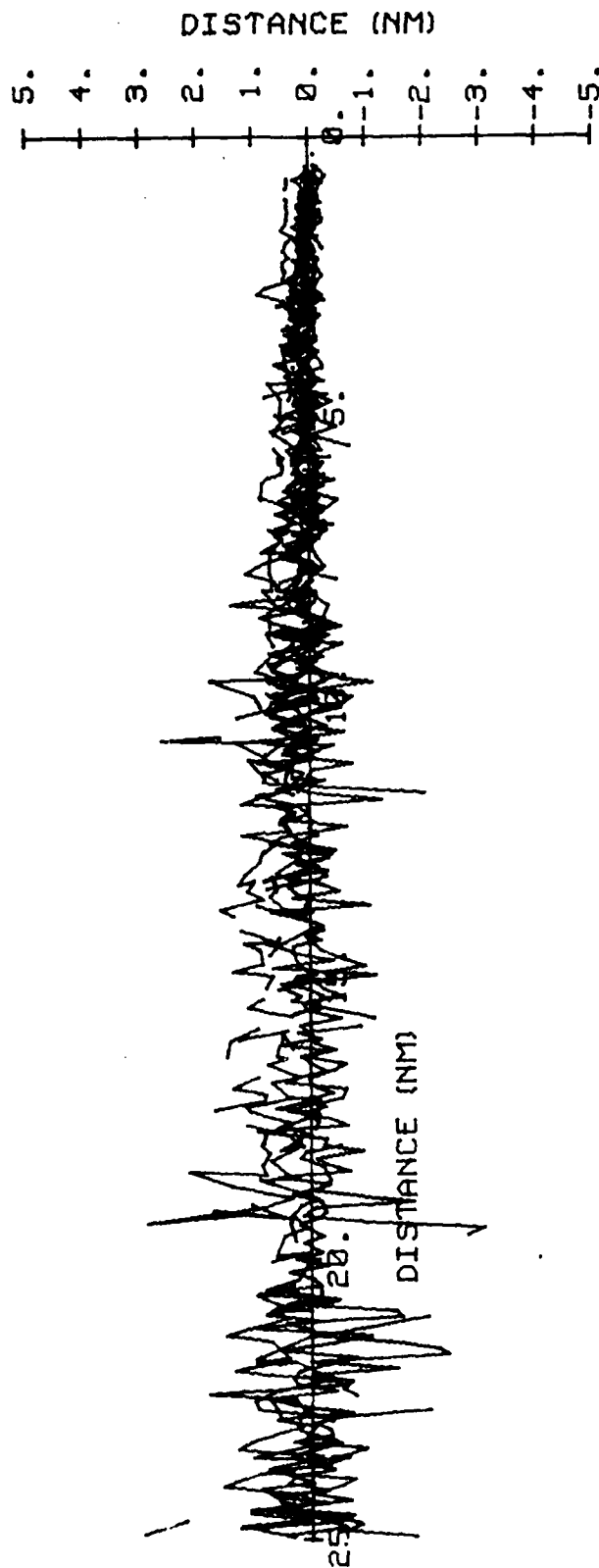
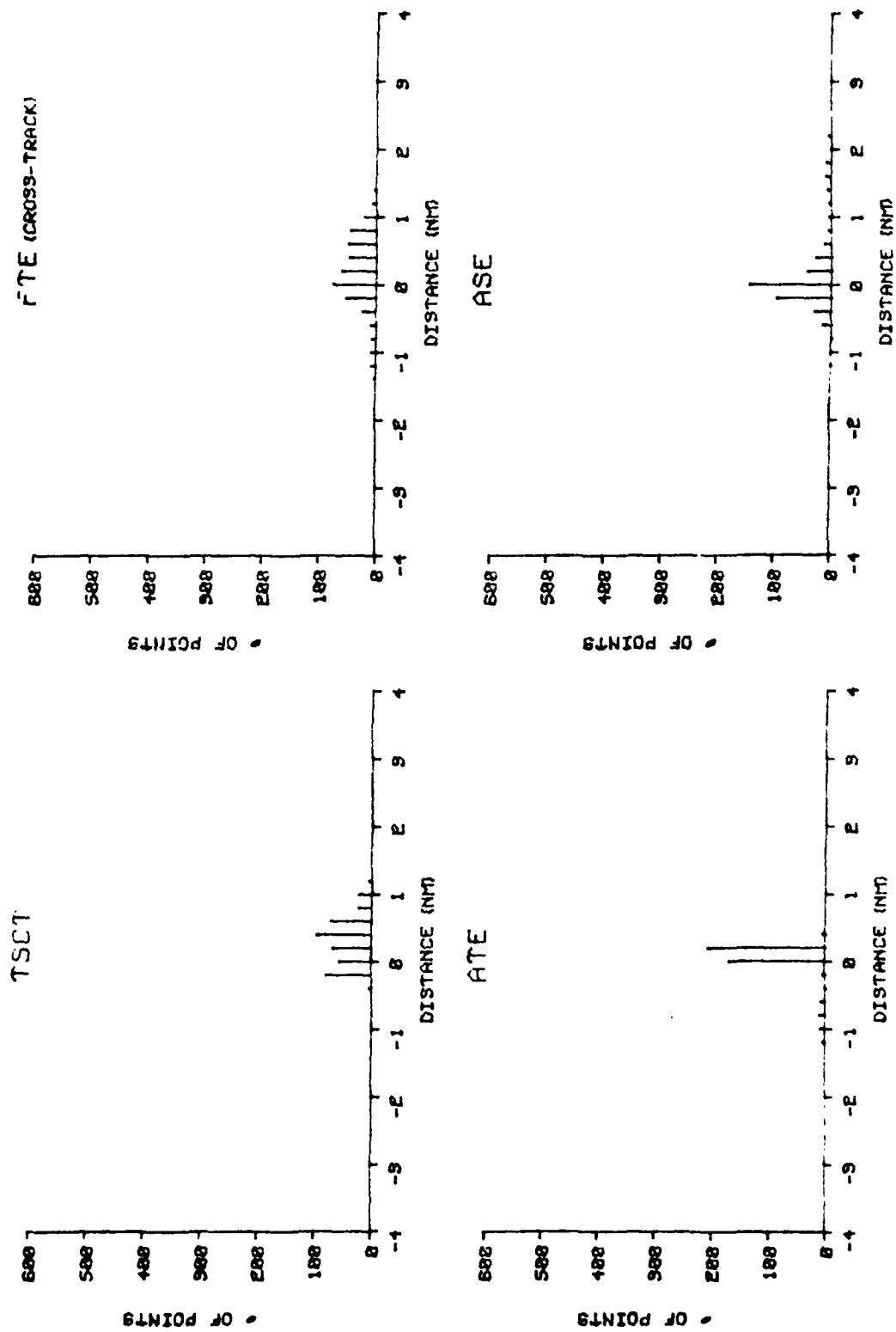
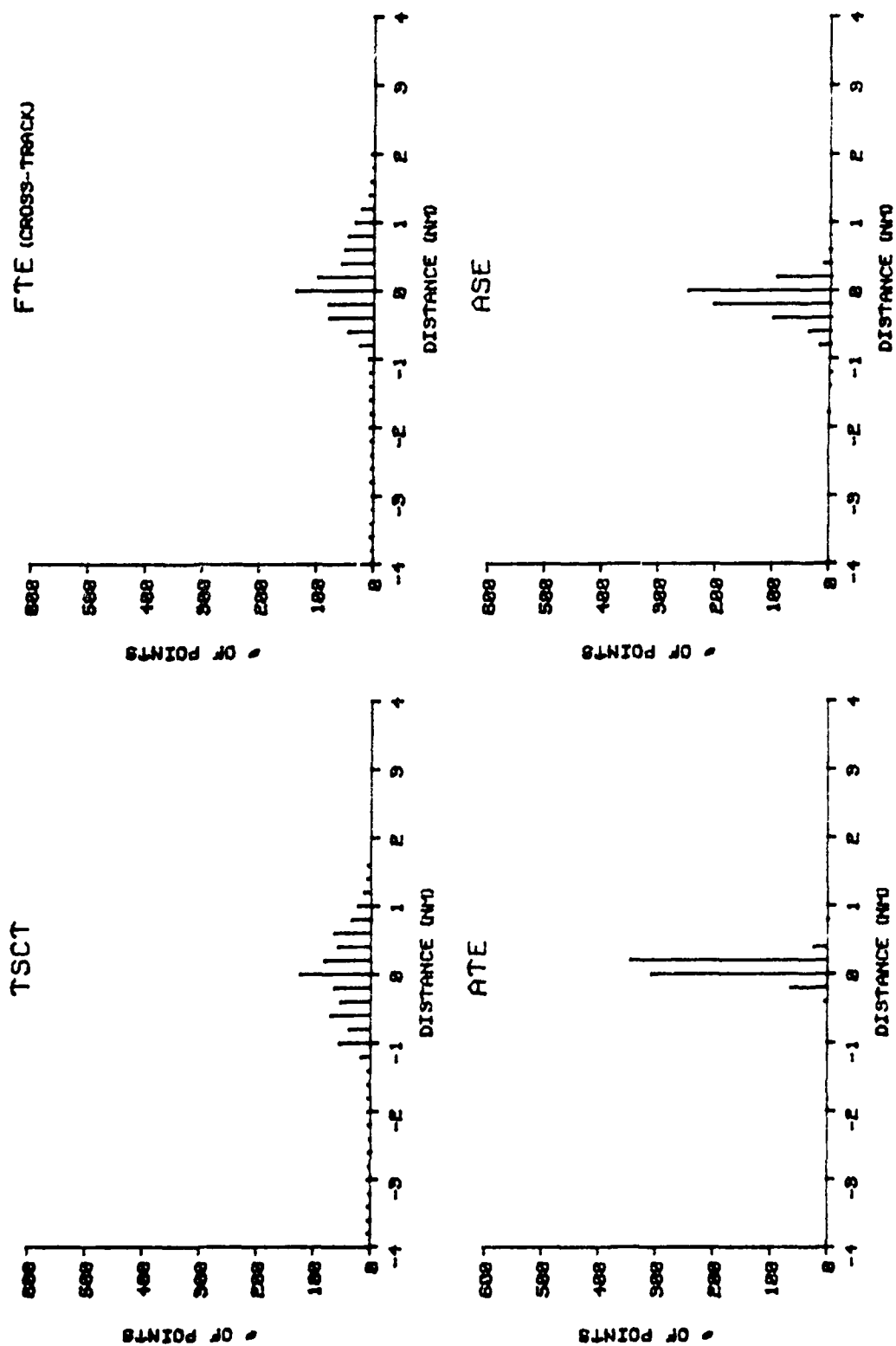


Figure 5.8 ARA Offshore Single Beacon Mode Airborne System Error



NOTE: Data Derived From 7 Approach Segments

Figure 5.9 Bendix RDR-1400A Offshore Site Skin Paint Mode Histograms



NOTE: Data Derived From 12 Approach Segments

Figure 5.10 Bendix RDR-1400A Offshore Site Single Beacon Mode Histograms

Table 5.14 NAFEC ARA Bendix RDR-1400A Skin Paint With Cursor
Offshore Approaches Error Analysis Log And
Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.1674	.2883	154	2
Short	-.0380	.3490	285	6
Total	.0340	.3430	439	8
<u>ARA ASE</u>				
Long	.7193	.6650	154	2
Short	-.0348	.2869	285	6
Total	.2297	.5811	439	8
<u>FTE</u>				
Long	-.0491	.7312	154	2
Short	-.0285	.2529	285	6
Total	-.0357	.4778	439	8
<u>TSCT</u>				
Long	.6702	.6262	154	2
Short	-.0634	.3290	285	6
Total	.1940	.5744	439	8
<u>IDENTIFIER</u>	<u>True Heading</u>		<u>Segment</u>	
7/19/79 -1	222		Long	
7/19/79 -2	222		Short	
7/19/79 -3	222		Short	
7/27/79 -2	222		Short	
7/27/79 -3	222		Short	
7/30/79 -1	222		Long	
7/30/79 -2	222		Short	
7/30/79 -3	222		Short	

number of data points and number of approach segments for four error quantities: ATE, ASE, FTE and TSCT. Table 5.14 shows in the ARA ATE case that the mean value is .0340 nm and the one-sigma is .3430 nm for all of the data points collected. These values correlate very closely to those ARA ATE values indicated in Table 5.10 (Section 5.3.1). Table 5.10 presented an ARA ATE mean of .0345 nm and a one-sigma of .2567 nm. Table 5.14 shows a mean ARA ASE value of .2297 nm and a one-sigma of .5811 nm for all of the approach segments. Once again the ARA ASE values from Table 5.10 are similar in magnitude to those seen for the skin paint with cursor testing (Table 5.14).

The Flight Technical Error (FTE) quantities indicated in Table 5.14 showed a mean value of -.0357 nm and a one-sigma of .4778 nm. The skin paint with cursor FTE is small both in the mean and one-sigma values compared to the non-cursor aided skin paint flights. Table 5.10 shows a mean FTE value of .0615 nm and a one-sigma value of .6350 nm. A reduction of .16 nm was achieved in the one-sigma numbers for all of the approach segments using the cursor technique. The Total System Cross Track (TSCT) error quantities presented in Table 5.14 showed a mean value of .1940 nm and a one-sigma of .5744 nm. These quantities indicate a decrease of .06 nm in the mean value for all of the approach segments (skin paint quantities presented in Table 5.10).

Table 5.15 summarizes in statistical quantities the Airborne Radar Approach Skin Paint with Cursor test data at one nautical mile intervals, starting at ten (10) nautical miles. The quantities are presented in both linear and angular terms. The FTE angular quantities at one nautical mile shows a mean of -4.9 degrees and a one-sigma of 8.4 degrees. The TSCT angular quantities at one nautical mile shows a mean of -3.2 degrees and a one-sigma of 8.9 degrees. Table 5.12 (Section 5.3.1) presented the one nautical mile statistical data for the skin paint mode. The FTE values presented in Table 5.12 shows a mean value of 5.7 degrees and a one-sigma of 14.0 degrees at one nautical mile. The cursor-aided approaches showed a marked decrease of 5.6 degrees in the one-sigma quantities and a decrease of .8 degrees in the mean value. The skin paint with cursor linear TSCT mean at one nautical mile is -.06 nm with a one-sigma of .16 nm. The linear FTE quantities presented in Table 5.15 show a mean value of -.09 nm and a one-sigma of .15 nm at one nautical mile.

Table 5.15 Bendix RDR-1400A Skin Paint With Cursor One Nautical Mile Aggregate Data

NM	FTG	---LINEAR ERRORS---				---ANGULAR ERRORS---			
		ATE	TSCT	FTE	ASE	TSCT	FTE	ASE	
1	6	.3164	-.0556	-.0855	.0299	-3.1339	-4.8881	1.7139	MEAN
		.4091	.1571	.1483	.1378	3.9259	8.4328	7.0178	STD
2	7	.1224	.0020	-.0317	.0380	.0560	-2.3339	2.7940	MEAN
		.2450	.2151	.1214	.2110	4.1399	3.4722	6.0296	STD
3	9	-.0225	.0196	-.0244	.0740	.9470	-.4658	1.4126	MEAN
		.4428	.3680	.0805	.8090	6.8974	1.5380	5.8818	STD
4	9	.0237	.1451	.0538	.0913	2.0789	.7701	1.3082	MEAN
		.4155	.4183	.2226	.2722	5.6494	3.1851	2.8925	STD
5	9	-.0085	.2071	.0182	.1896	2.3805	.2090	2.1717	MEAN
		.3469	.5074	.2433	.4704	5.7941	2.8202	5.3743	STD
6	9	.0212	.1961	.0716	.1248	1.8743	.6840	1.1912	MEAN
		.0840	.5802	.5084	.5624	5.5234	4.8130	5.3552	STD
7	9	.0380	.2344	.1217	.1127	1.9182	.9963	.9224	MEAN
		.0526	.6941	.5240	.7272	5.6629	4.2810	5.9309	STD
8	9	.1165	.2710	-.0922	.2632	1.9390	-.6605	2.9294	MEAN
		.2425	.4766	.2962	.8034	4.8241	2.1206	7.7344	STD
9	7	.0802	.3315	-.0313	.3838	2.2367	-.2026	2.4389	MEAN
		.1496	.8317	.2454	.8053	5.2797	1.5620	5.1130	STD
10	4	.0005	.7485	.1411	.6013	4.2021	.8141	3.4416	MEAN
		.1977	.7149	.3906	.6801	4.0890	2.2369	3.8904	STD

The skin paint linear FTE values presented in Table 5.12 show a mean value of .10 nm and a one-sigma of .25 nm resulting in a decrease of .10 nm for the one-sigma values using the cursor aided techniques. Table 5.15 shows a mean TSCT of .00 nm and a one-sigma of .22 nm at two nautical miles. TSCT mean and one-sigma values indicated at two nautical miles for the skin paint mode testing are .14 nm and .34 nm, respectively. These values show a decrease of .14 nm in the mean value and a decrease of .12 nm in the one-sigma value. As before the ATE linear values indicated in Table 5.15 are consistently small for all ranges.

Figure 5.11 summarizes in graphical form the Total System Cross Track Error (TSCT) of all the approaches flown at the offshore site in the skin paint with cursor mode. The plot shows that outside of ten (10) nautical miles the maximum deviation from intended course is -1.2 nm. Between ten (10) and five (5) nautical miles the maximum error indicated is -1.6 nm and within five (5) nautical miles the maximum error shown is -.8 nm. The quantities between ten (10) and five (5) miles are well within the ± 4.0 nm route width established by RTCA SC-133. Within five (5) nautical miles the maximum value of .8 nm is within the ± 1.7 nm airspace requirement established by SC-133.

Figure 5.12 summarizes in plot form the FTE of all the approaches flown at the offshore site in the skin paint with cursor mode. The large quantities of 6.0 nm outside of fifteen (15) nautical miles stem from an approach where the wrong target was tracked at the beginning of the approach. Figure 5.13 presents a plot of TSCT and FTE vs. along track distance which shows the approach where the wrong target was tracked until approximately eighteen (18) nautical miles from the intended target. Between ten (10) and five (5) nautical miles the maximum deviation in error is -1.5 nm and within five (5) nautical miles the maximum deviation in error is -.5 nm. These values show marked improvement over those mentioned in Figure 5.5 (Section 5.3.1). With the exception of the two approaches flown to the wrong target the figure indicates a maximum deviation of -1.2 nm in the skin paint mode, which indicates a .7 nm improvement in the 5 nm area due to the cursor technique.

ARA APPROACHES -- OFFSHORE SITE
 BENDIX RDR-1400A SKIN PAINT W/ CURSOR MODE

9 APPROACHES
 AGGREGATE TSOT

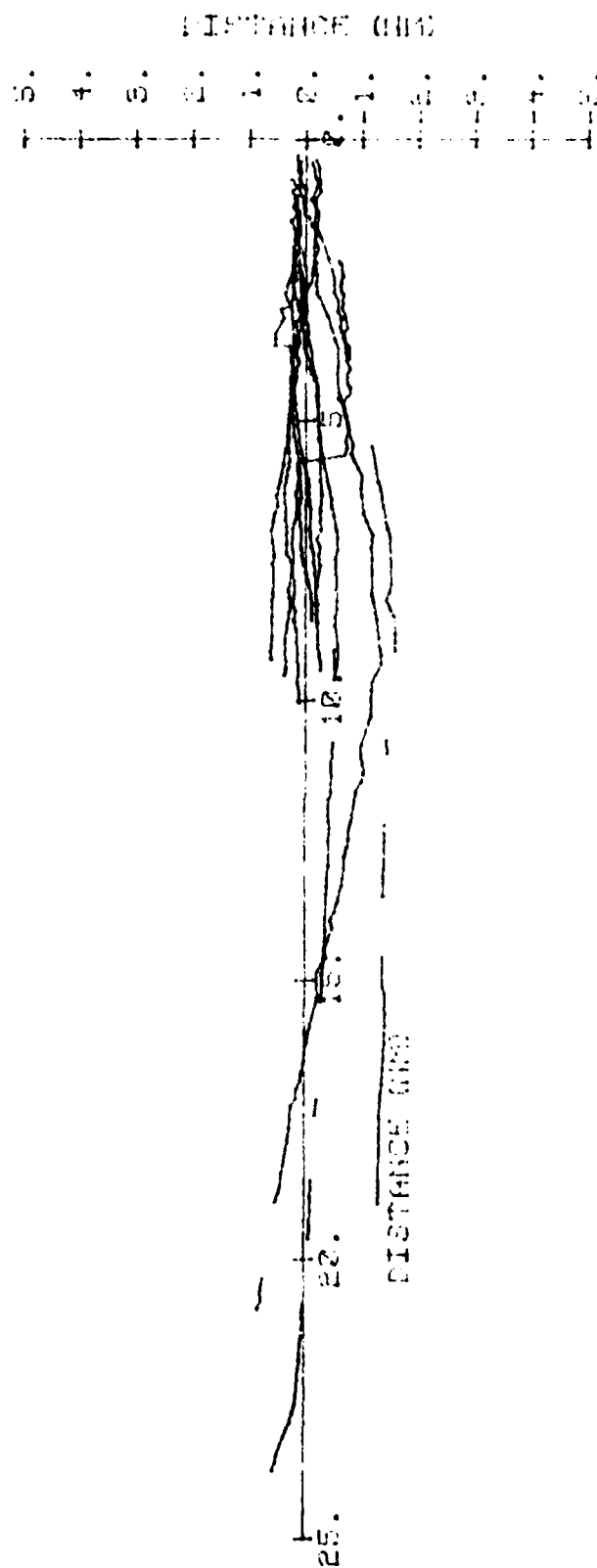


Figure 5.11 ARA Offshore Skin Paint With Cursor Mode Total System Cross Track Error

ARA APPROACHED -- OFFSHORE SITE
 BENIX RRS-1420A SKIN PAINT M. CURSOR MODE

9 APPROACHED
 AGGREGATE FTE

WRONG TARGET TRACKED AT
 THE START OF THE APPROACH

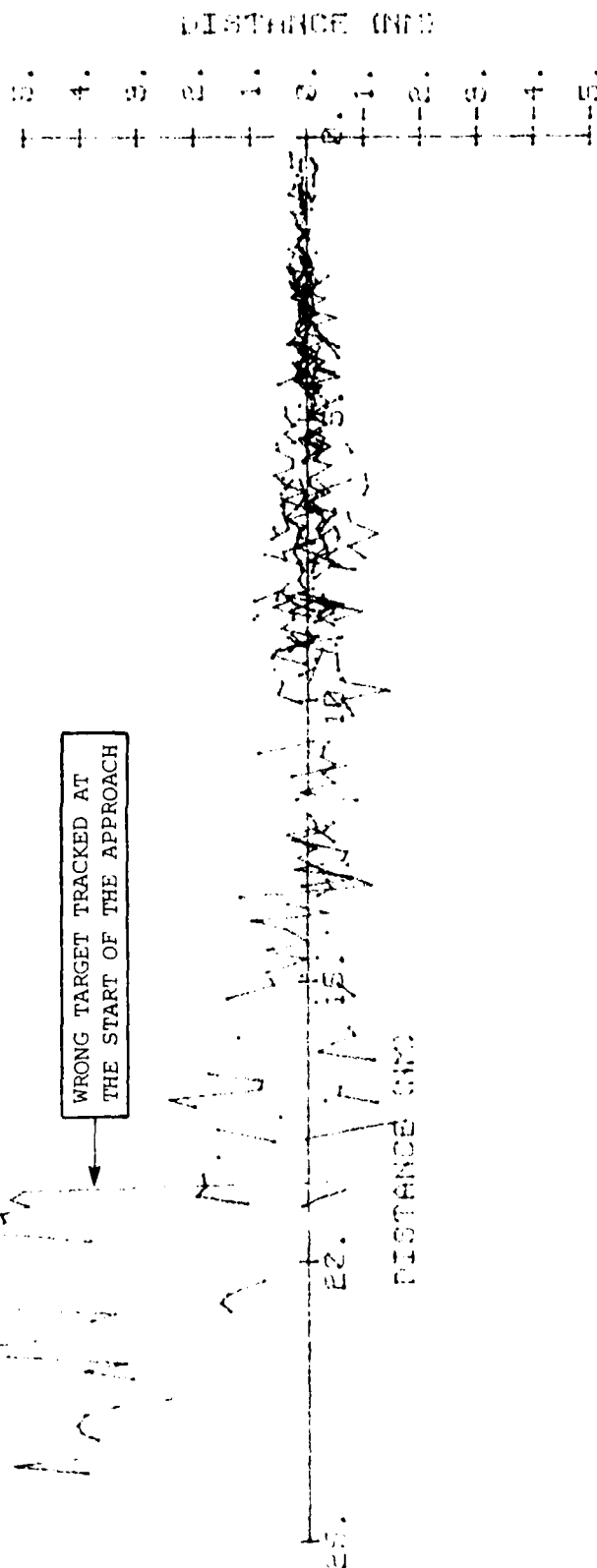
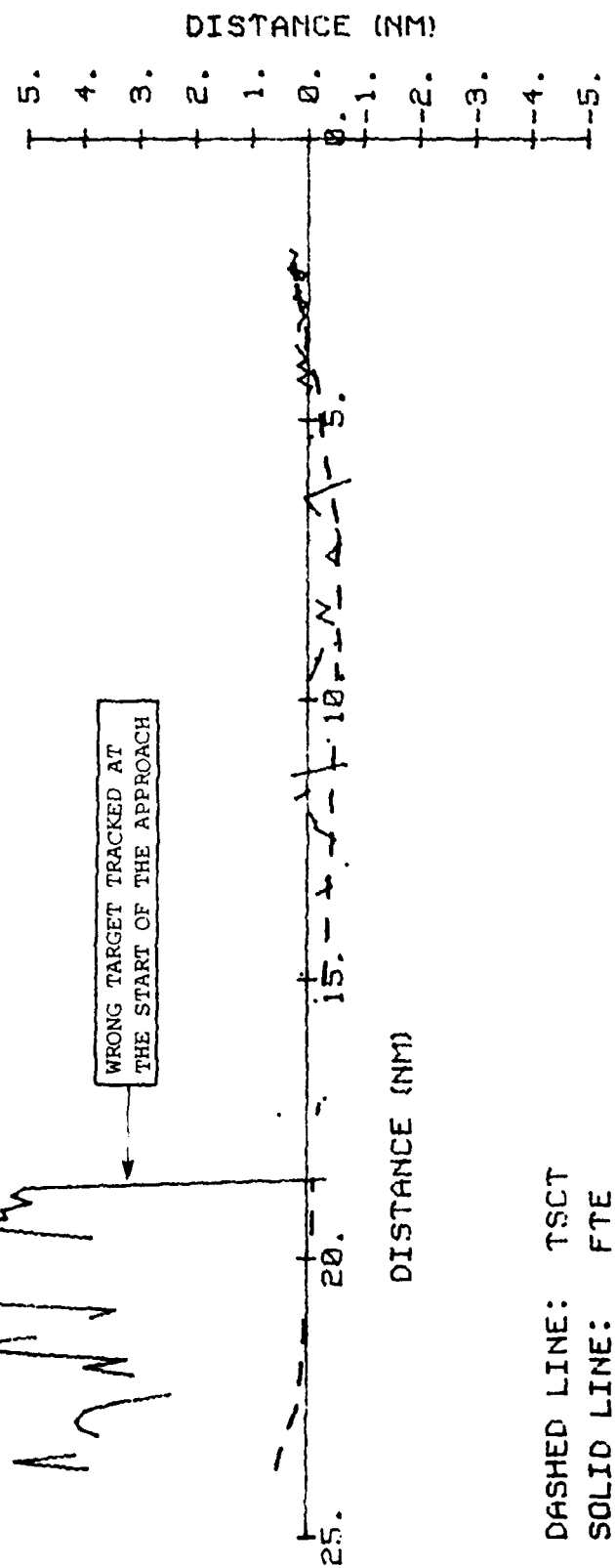


Figure 5.12 ARA Offshore Skin Paint With Cursor Mode Flight Technical Error

007271A

ARA APPROACH -- OFFSHORE SITE
BENDIX RDR-1400A SKIN PAINT W/CURSOR MODE

FLIGHT DATE: 7/27/79 - 1
STRAIGHT IN -- 222 DEG. TN



DASHED LINE: TSCT
SOLID LINE: FTE

Figure 5.13 ARA Offshore Site TSCT And FTE Plot: Direct Straight Approach Flown
27 July 1979

Figure 5.14 is a graphical representation of the offshore site skin paint with cursor Airborne System Error (ASE). Again because the wrong target was tracked on one approach outside of ten (10) nautical miles the maximum error quantity indicated is -6.1 nm. Between ten (10) and five (5) nautical miles the maximum error is -2.2 nm. Within five (5) nautical miles the maximum error shown is only -.7 nm. The Airborne System Error once more is consistently small, which indicates the airborne radar is reliable and offers good repeatability.

Figure 5.15 presents histograms of ARA TSCT, FTE, ASE and ATE for the skin paint with cursor approaches flown at the offshore site. Only data within 10 nm of the target is included. These histograms represent the error quantity distributions for the four ARA error quantities. The TSCT histogram shows that the quantities appear skewed to the right. The FTE histogram appears to be normal. The ASE distribution appears skewed slightly to the left while the ATE quantities appear skewed to the right.

5.3.3 Airport Site: Performance Enhancement In The Beacon Mode Using The Cursor Technique

The heading error cursor technique is based on a minor airborne system modification (Section 4.1.1). The technique works equally well in both the landside and offshore environments. As mentioned in Section 5.3.1 the skin paint cursor aided approaches showed a decrease in the Total System Cross Track errors (TSCT) and Flight Technical Error (FTE) quantities. The intent of this subsection is to show that a marked decrease is also present in cursor aided beacon mode TSCT and FTE quantities.

Table 5.16 summarizes the results of the Airborne Radar Approach testing conducted at the airport site in the beacon with cursor mode. The airport site utilized the NAFEC terminal area with the beacon placed on the threshold of runway 26. An extended centerline of the runway offered the approach course to the beacon. This table is similar to the ones presented in Sections 5.3.1 and 5.3.2, and summarizes the mean values, standard deviations and the number of data points in four specific areas.

Table 5.16 indicates a mean ARA ATE quantity of .1970 nm and a one-sigma of .1825 nm. The results of the ARA ASE quantities shows a mean value of -.1054 nm and a one-sigma of .4863 nm. These data were calculated from a sample size of 952 data points or 17 approach segments.

ARA APPROACHES -- OFFSHORE SITE
 BENDEX RCR-1420A SKIN PAINT VMCURSOR MODE

2 APPROACHES
 AGGREGATE ASE

DISTANCE (NM)
 5. 4. 3. 2. 1. 0. 1. 2. 3. 4. 5.

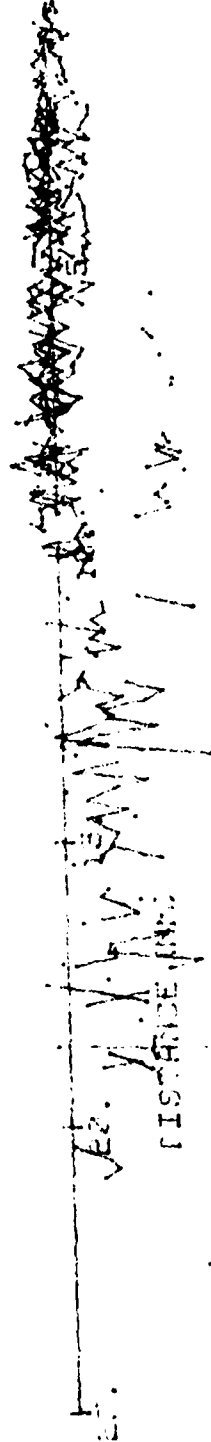
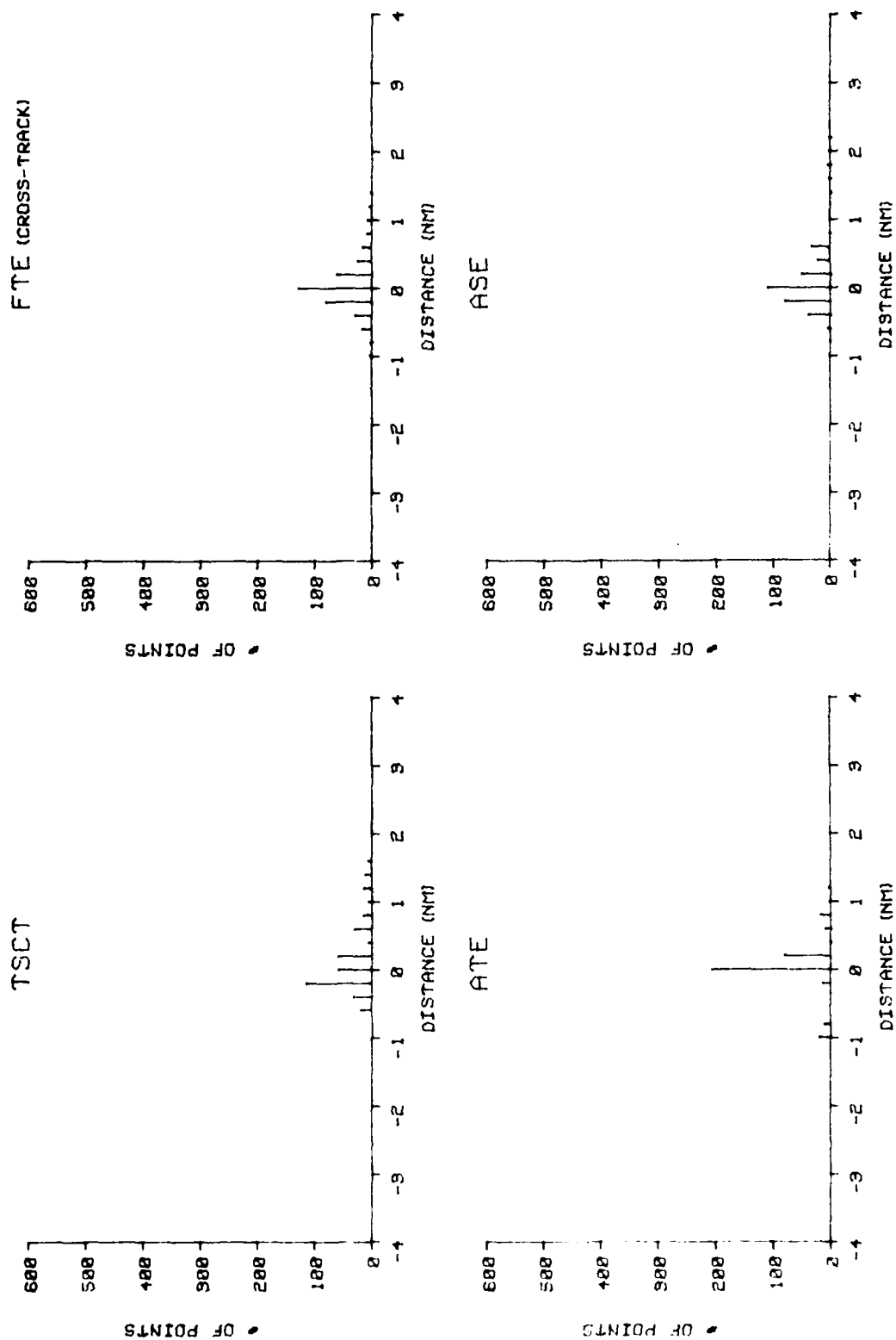


Figure 5.14 ARA Offshore Skin Paint With Cursor Airborne System Error



NOTE: Data Derived From 8 Approach Segments

Figure 5.15 Bendix RDR-1400A Skin Paint With Cursor Mode Histograms

Table 5.16 NAFEC ARA Bendix RDR-1400A Beacon With Cursor
Airport Approaches Error Analysis Log And
Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.1724	.1548	524	5
Short	.2271	.2077	428	12
Total	.1970	.1825	952	17
<u>ARA ASE</u>				
Long	-.2079	.6115	524	5
Short	.0200	.2002	428	12
Total	-.1054	.4863	952	17
<u>FTE</u>				
Long	.4744	.9320	524	5
Short	-.0083	.3187	428	12
Total	.2574	.7623	952	17
<u>TSCT</u>				
Long	.2665	.7194	524	5
Short	.0118	.2186	428	12
Total	.1520	.5676	952	17
<u>IDENTIFIER</u>	<u>RWY</u>	<u>True Heading</u>	<u>Segment</u>	
8/2/79 AM-1	26	252	Long	
8/2/79 AM-2	26	252	Short	
8/2/79 AM-3	08	72	Long	
8/2/79 AM-4	08	72	Short	
8/2/79 AM-5 Initial	26	252	Long	
8/2/79 AM-5 Final	08	72	Short	
8/2/79 AM-6 Initial	26	252	Short	
8/2/79 AM-6 Final	08	72	Short	
8/2/79 AM-7 Final	26	252	Short	
8/2/79 PM-1	26	252	Long	
8/2/79 PM-2 Initial	26	252	Short	
8/2/79 PM-2 Final	08	72	Short	
8/2/79 PM-3 Initial	08	72	Short	
8/2/79 PM-3 Final	26	252	Short	
8/2/79 PM-4 Initial	08	72	Short	
8/2/79 PM-4 Final	26	252	Short	
8/6/79 -1	08	72	Long	

Table 5.17 presents the results of the ARA testing at the airport site in the single beacon mode (Section 5.3.1, Reference 1). The error analysis log and statistical summary reflect only the long and short segments so that a direct comparison could be established. The offset segments were omitted from the totals because there were no offset approaches flown during the beacon with cursor testing.

Table 5.17 shows a mean ARA ATE value of .1168 nm and a one-sigma of .1804 nm for all of the approach segments flown. The ARA ASE quantities shows a mean and one-sigma value of -.0554 and .4715 nm, respectively. These values compare quite favorably with the ATE and ASE values presented in Table 5.16. In fact, for the Bendix Radar System, in general regardless of the operational mode the Airborne System errors have been well within acceptable limits.

The FTE quantities indicated in Table 5.16 (beacon with cursor) shows a total mean value of .2574 nm and a one-sigma of .7623 nm. Table 5.17 shows that the total mean and one-sigma quantities are .6279 nm and 1.4361 nm, respectively. A reduction of .37 nm in the mean quantity and .67 nm in the one-sigma quantity is evident from these results using the cursor technique during the approach. The cursor technique offers the pilot an immediate indication of track angle error. With this the pilot can determine his drift angle and course orientation. The cursor eliminates the "second-guessing" involved in determining track orientation, therefore, reducing the tendency to "home" to the station. In effect it gives the radar "omnidirectional" capabilities.

The TSCT quantities presented in Table 5.16 showed a mean value of .1520 nm and a one-sigma of .5676 nm for all of the approach segments flown. Table 5.17 indicates a total mean TSCT quantity of .5725 nm and a one-sigma of 1.3593 nm. The Total System Cross Track errors were reduced by .42 nm in the mean value and by .79 nm in the one-sigma quantity. The procedure turn executed during the single beacon testing induced some initial errors (see Reference 1 for details), but the pilot still had a tendency to "home" to the station without the aid of the cursor. Later, in this subsection a case will be presented where the aircraft was intentionally offset to a predetermined position so as to duplicate the initial conditions given to the pilot in an earlier approach. A direct comparison of the approaches will show that with the aid of the cursor the pilot was able to acquire the intended track in a short period of time and fly directly to the beacon.

Table 5.17 NAFEC ARA Bendix RDR-1400A Beacon Mode
Airport Approaches Error Analysis Log
And Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.1209	.2349	263	4
Short	.1131	.1112	294	7
Total	.1168	.1804	557	11
<u>ARA ASE</u>				
Long	.0168	.6336	263	4
Short	-.1200	.2324	294	7
Total	-.0554	.4715	557	11
<u>FTE</u>				
Long	.8908	1.9144	263	4
Short	.3927	.7203	294	7
Total	.6279	1.4361	557	11
<u>T SCT</u>				
Long	.9076	1.8025	263	4
Short	.2727	.6402	294	7
Total	.5725	1.3593	557	11
<u>IDENTIFIED</u>	<u>RWY</u>	<u>True Heading</u>	<u>Segment</u>	
11/03/78 -1 Initial	26	253	Long	
11/03/78 -3 Initial	08	073	Long	
12/13/78 PM-1 Initial	26	253	Long	
12/13/78 PM-1 Final	08	073	Short	
12/13/78 PM-2 Initial	26	253	Short	
12/13/78 PM-2 Final	08	073	Short	
12/13/78 PM-3 Initial	08	073	Long	
12/13/78 PM-3 Final	26	253	Short	
12/14/78 -4 Initial	08	073	Short	
12/14/78 -4 Final	26	253	Short	
12/14/78 -5	26	253	Short	

Tables 5.18 and 5.19 summarizes in statistical quantities the Airborne Radar Approach test data at one nautical mile intervals, starting at ten (10) nautical miles. The quantities in Table 5.18 reflect data collected in the single beacon with cursor mode and the data in Table 5.19 shows data obtained in the airport single beacon mode testing. The quantities in both tables were collected in both linear and angular terms, for both long and short segments. The angular FTE beacon with cursor quantities presented in Table 5.18 showed a mean value of -2.3 degrees and a one-sigma of 10.9 degrees at one nautical mile. The angular mean and one-sigma TSCT beacon with cursor quantities at one nautical mile are -.33 degrees and 10.6 degrees, respectively. At one nautical mile in Table 5.19 the FTE single beacon mean is 4.3 degrees and the one-sigma value is 37.7 degrees. The large one-sigma FTE can be attributed to the fact that on three of the approaches the pilot missed the target by .8 of a nautical mile. The TSCT angular quantities in the single beacon mode at one nautical mile shows a mean value of 4.0 degrees and a one-sigma of 34.8 degrees. The FTE and TSCT angular quantities indicated in Table 5.18 are considerably smaller than those presented in Table 5.19, between one and three nautical miles for both the mean and one-sigma values. The smaller angular quantities indicated in Table 5.18 once again prove that the cursor technique affords the pilot the ability to track to the beacon with good accuracy and repeatability.

The linear error quantities in Tables 5.18 shows a mean TSCT value of .00 nm and a one-sigma of .19 nm at one nautical mile. The FTE beacon with cursor linear quantities indicates a mean value of -.04 nm and a one-sigma of .19 nm, again at one nautical mile. Table 5.19 shows an increase in the TSCT and FTE linear quantities, where the TSCT mean and one-sigma values are .07 nm and .70 nm, respectively, and the FTE mean and one-sigma value are .08 nm and .77 nm, respectively. At seven (7) nautical miles Table 5.19 shows a mean TSCT linear quantity of .40 nm and a one-sigma of 1.26 nm. The FTE quantities at seven (7) nautical miles in Table 5.19 indicates a mean value of .50 nm and a one-sigma of 1.30 nm. Other linear TSCT and FTE beacon with cursor quantities presented in Table 5.18 show that the quantities are consistently small. The ATE and ASE quantities presented in both tables are consistently small at all range intervals.

Table 5.18 Bendix RDR-1400A Beacon With Cursor One Nautical Mile Aggregate Data

-----LINEAR ERRORS-----I-----ANGLE/10K ERRORS-----I									
NP	PIC	ATE	PLC	FILE	AGE	FILE	AGE	FILE	AGE
1	1	.2181	.0095	.0402	.0049	.3327	.0081	1.9749	MEAN
		.1919	.1885	.1929	.1272	10.5251	10.9164	7.2820	STD
2	16	.2201	.0110	-.0201	.0050	.3404	.6615	1.0015	MEAN
		.1735	.2327	.2924	.1542	6.7272	8.2162	4.4111	STD
3	17	.2317	.0560	.0516	.0013	1.0245	.9557	.1003	MEAN
		.1520	.2471	.2601	.1144	4.7082	5.5229	2.1346	STD
4	18	.2242	.0313	.0537	.0376	1.1651	.7697	.3954	MEAN
		.1679	.1747	.2622	.1919	3.6127	5.1741	2.7449	STD
5	11	.2340	.1150	.0937	.0483	1.1113	.7532	.5647	MEAN
		.1036	.2112	.4261	.2387	2.5612	4.6794	3.0827	STD
6	10	.2274	.0667	.2023	-.1327	.6350	1.9315	-1.5347	MEAN
		.1162	.4128	.4650	.4145	8.9356	4.4316	5.9524	STD
7	6	.1929	.1957	.4654	-.3093	1.2733	3.8041	-2.5310	MEAN
		.0892	.5647	.5224	.9582	4.6121	4.2676	4.5596	STD
8	5	.1760	.1344	.4803	-.2464	.9623	3.1502	-2.1771	MEAN
		.1165	.6628	.6854	.5784	4.7260	4.8071	1.1511	STD
9	5	.1733	.1983	.5251	-.4267	.6070	3.4024	-2.7113	MEAN
		.0668	.6057	.8012	.8280	3.8700	7.6870	5.1227	STD
10	4	.1477	.0517	.3942	-.5775	.8213	3.6286	-3.3041	MEAN
		.1017	.5823	.6487	1.0622	3.3326	7.7651	2.0621	STD

Table 5.19 Bendix RDR-1400A Airport Site Beacon Mode One Nautical Mile Aggregate Data

NM	PR	LINEAR ERRORS										ANGULAR ERRORS									
		ALC	TCUT	FL	ASC	TR	TR	TR	TR	TR	TR										
1	1	1.129	0.699	0.734	0.0054	0.7719	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1	1.102	0.693	0.735	0.1007	0.6433	0.7719	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1	1.113	0.127	0.130	-0.0771	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	1	0.950	0.724	0.808	0.1721	0.1139	0.8844	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	1	1.129	0.101	-0.000	-0.0629	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	1	1.000	0.290	0.674	0.1236	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	1	1.000	0.101	0.126	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	1	1.000	0.290	0.172	0.1521	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	1	1.129	0.076	0.130	-0.0679	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	1	1.129	0.489	0.519	0.2871	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	1	1.129	0.101	0.850	-0.1779	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	1	1.129	0.867	1.017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	1	1.129	0.374	0.970	-0.1211	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	1	1.129	1.261	1.000	0.2420	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	1	1.129	0.000	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	1	1.129	0.100	0.706	0.2072	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	1	1.129	0.144	0.042	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	1	1.129	0.211	0.004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	1	1.129	0.444	0.000	-0.1164	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	1	1.129	0.795	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5.20 summarizes the mean and one-sigma Letdown Error (LDE) quantities obtained during the single beacon with cursor approach testing conducted at the airport site. These values quantify the ability of the pilot to utilize the ARA system to define and identify a step-down fix. Table 5.20 represents values sampled at the 5.0 nautical mile Initial Approach Fix (IAF) and at the 2.0 nautical mile Final Approach Fix (FAF). The profiles shown earlier in Section 4.2 indicate that at the IAF the pilot initiated a descent from 1000 feet to 500 feet and at the FAF he initiated a descent from 500 feet to 200 feet. The error quantities were determined by correlating the airborne radar's indicated approach fix position with time. Next, using the EAIR tracking data printout it was then determined when a descent was actually initiated and this time was noted. Then this time was correlated with the airborne data and the indicated beacon position noted. The difference between displayed distance and the prescribed letdown point was then computed. (Distance to the target was computed as positive). The mean value at the IAF shows that the pilot initiated his descent .09 nm before passing the fix. The one-sigma value at the IAF was .54 nm. The mean value at the FAF shows that the pilot started his descent .09 nm before passing the fix with a one-sigma value of .22 nm. It is interesting to note that the values are similar in magnitude and of the same sign, indicating that at the IAF and FAF the pilot anticipated his position. The single beacon airport LDE quantities (Reference 1 - Section 5.3.1) showed that at the IAF the pilot started his descent .36 nm after passing the fix. At the FAF the pilot started a descent .18 nm after passing the fix in the airport single beacon testing. It should be noted that during the single beacon testing the FAF was at 1.5 nm instead of 2.0 nm. This change was implemented so that the pilot could have more time to establish his final airspeed (50 Kts.), altitude (200') and crab angle. Since during the cursor testing the pilot started his descent slightly before reaching the fix this indicates that the decrease in workload afforded by using the cursor allowed the pilot to concentrate more on his along track position and utilize the radar for more accurate approach fix identification.

Table 5.20 Beacon With Cursor Letdown Error Quantities

Approach Position	Error Magnitudes	
	Mean nm	+1 σ nm
IAF (5.0 nm Fix)	-.0911	.5368
FAF (2.0 nm Fix)	-.0908	.2207

Figure 5.16 summarizes in graphical form the Total System Error of all the approaches flown at the airport site in the beacon with cursor mode. The plot shows that outside of ten (10) nautical miles the maximum deviation from intended track is -4.2 nm. This approach has a large initial error because on this particular approach the aircraft was initially intentionally offset from the intended track. Figure 5.17 presents the approach which was flown in 3 November 1978 during the single beacon approach testing at NAFEC. The initial approach position of this approach was computed so that the aircraft could be vectored to this position by ATC. From this position the approach was initiated using the cursor technique, to prove that when the cursor is utilized the tendency to "home" to the station is eliminated. Figure 5.17 shows that without the aid of the cursor the pilot had difficulty in acquiring the intended track and tracking inbound along the desired course. Figure 5.18 shows that with the aid of the cursor the pilot quickly identified his relative course position and then flew directly towards the intended course and tracked the beacon inbound with good precision. The segments presented in Figure 5.17 and 5.18 are initial segments of the overhead straight procedure.

Between ten (10) and five (5) nautical miles Figure 5.16 shows a maximum deviation from intended course of -1.0 nm. This quantity is well within the four (4) nautical mile airspace requirement established by the RTCA SC-133 MOPS. Inside of five (5) nautical miles the maximum deviation from intended course is -.8 nm, which again is within the required airspace limits of +1.7 nm at the Missed Approach Point (MAP) set by the RTCA SC-133 MOPS.

ARA APPROACHES --- AIRPORT SITE
 BENDIX RDR-1400A BEACON W/CURSOR MODE

17 APPROACHES
 AGGREGATE TSCT

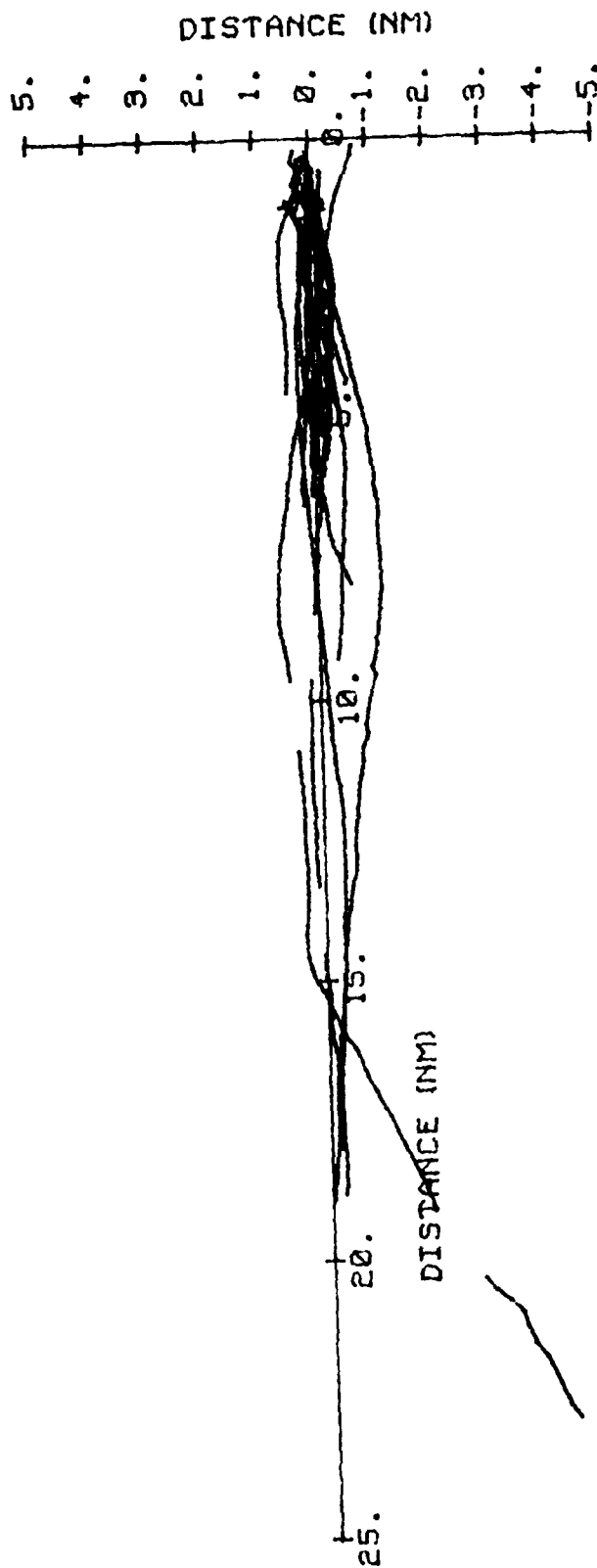


Figure 5.16 ARA Airport Single Beacon With Cursor Mode Total System Cross Track Error

011033

ARA APPROACH -- AIRPORT SITE
BENDIX RDR-1400A SINGLE BEACON MODE

FLIGHT DATE: 11/3/78 - 3
INITIAL SEGMENT -- 72 DEG. TN

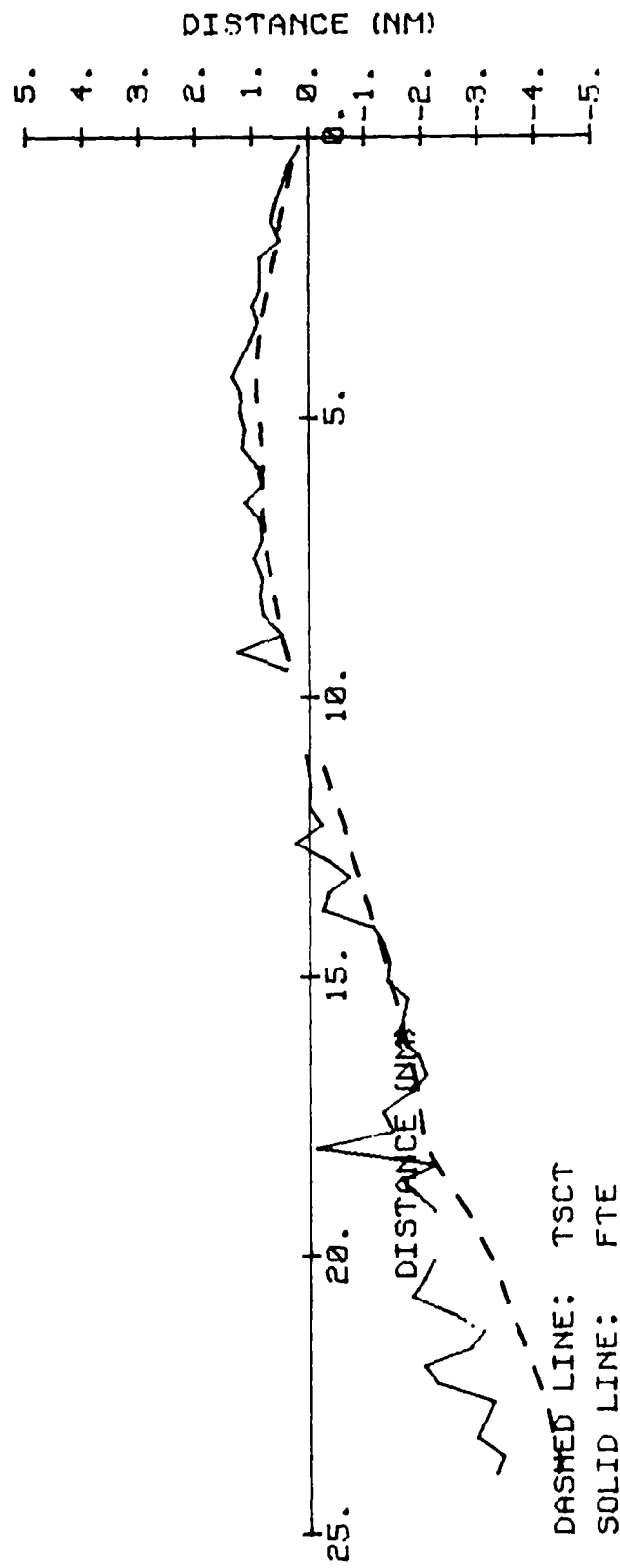


Figure 5.17 Initial Segment Of An Overhead Straight Approach Flown On 3 November 1978

08061P1

ARA APPROACH -- AIRPORT SITE
BENDIX RDR-1400A BEACON W/CURSOR MODE

FLIGHT DATE: 8/8/79-1 PM
INITIAL SEGMENT -- 72 DEG. TN

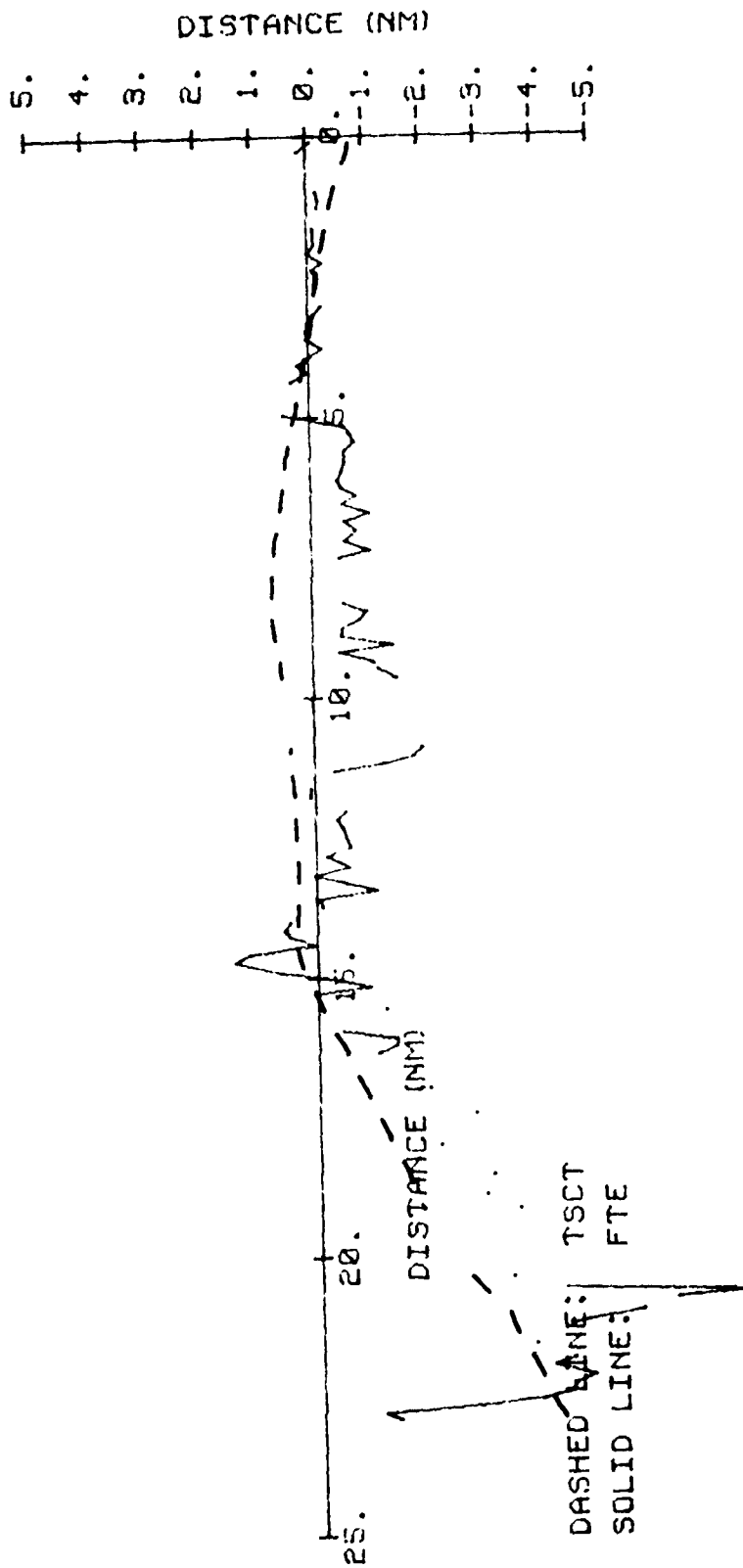


Figure 5.18 Intentional Offset Approach Flown On 6 August 1979

Figure 5.19 summarizes in graphical form the Total System Error of all the approaches flown in the single beacon mode at the airport site. The plot shows that between five (5) and ten (10) nautical miles from the beacon the maximum deviation from intended track is -2.5 nm. This deviation is 1.5 miles greater than -1.0 nm deviation shown in the same range interval in Figure 5.16, utilizing the cursor technique. Within five (5) nautical miles the maximum deviation from intended course is -1.3 nm, which is .5 nautical miles greater than the beacon with cursor plot indicates within five (5) miles. All of the approaches in Figure 5.19 indicate a tendency to "home" to the station whereas Figure 5.16 shows no such tendencies.

Figures 5.20 and 5.21 are plots of Flight Technical Error (FTE) vs. distance along the desired track, for all the approaches flown at the airport site in the single beacon and single beacon with cursor modes. Figure 5.20 shows that outside of ten (10) nautical miles the largest FTE beacon with cursor quantity indicated is -2.0 nm. The large -7.5 nm quantity at 22 nm is a result of the intentional offset approach executed during this phase of testing. Figure 5.21 shows numerous large error quantities outside of ten (10) nautical miles. These large FTE single beacon error quantities can be attributed to two things; inadequate initial course acquisition procedures and the pilot having a tendency to "home" to the station. Between five (5) and ten (10) nautical miles the maximum error indicated in Figure 5.20 is -1.7 nm and within five (5) miles the maximum FTE beacon with cursor error shown is -1.5 nm.

Figures 5.22 and 5.23 are plots of ARA Airborne System Error (ASE). Figure 5.22 presents the aggregate ASE quantities for the single beacon with cursor approach testing conducted at the airport site. Figure 5.23 presents the aggregate ASE quantities for the single beacon testing conducted during the period from October 1978 to December 1978 at the airport site (Reference 1). The ASE quantities shown in both figures are relatively small in comparison to the TSCT and FTE quantities shown in earlier figures. Most of the Airborne System Errors lie within a .2 nm region. Large spikes indicated on both plots are due to a rapid change in aircraft heading without the radar display having time to update. As mentioned earlier the ASE quantities for all areas of testing are quite small, proving the radar system offers good accuracy and repeatability.

ARA APPROACHES -- AIRPORT SITE
BENDIX RDR-1400A SINGLE BEACON MODE

11 APPROACHES
AGGREGATE TSCT

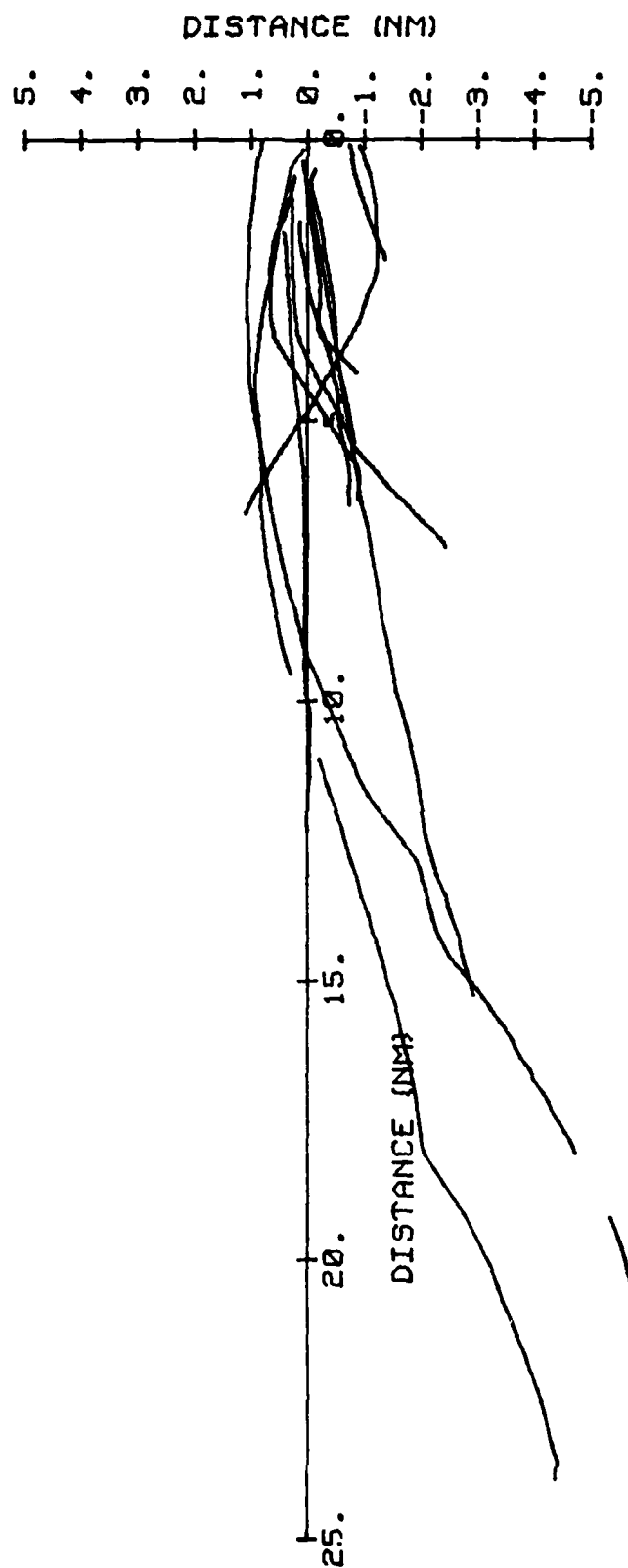


Figure 5.19 ARA Airport Single Beacon Approach Total System Cross Track Error

ARA APPROACHES -- AIRPORT SITE
 BENDIX RDR-1400A BEACON W/CURSOR MODE

17 APPROACHES
 AGGREGATE FTE

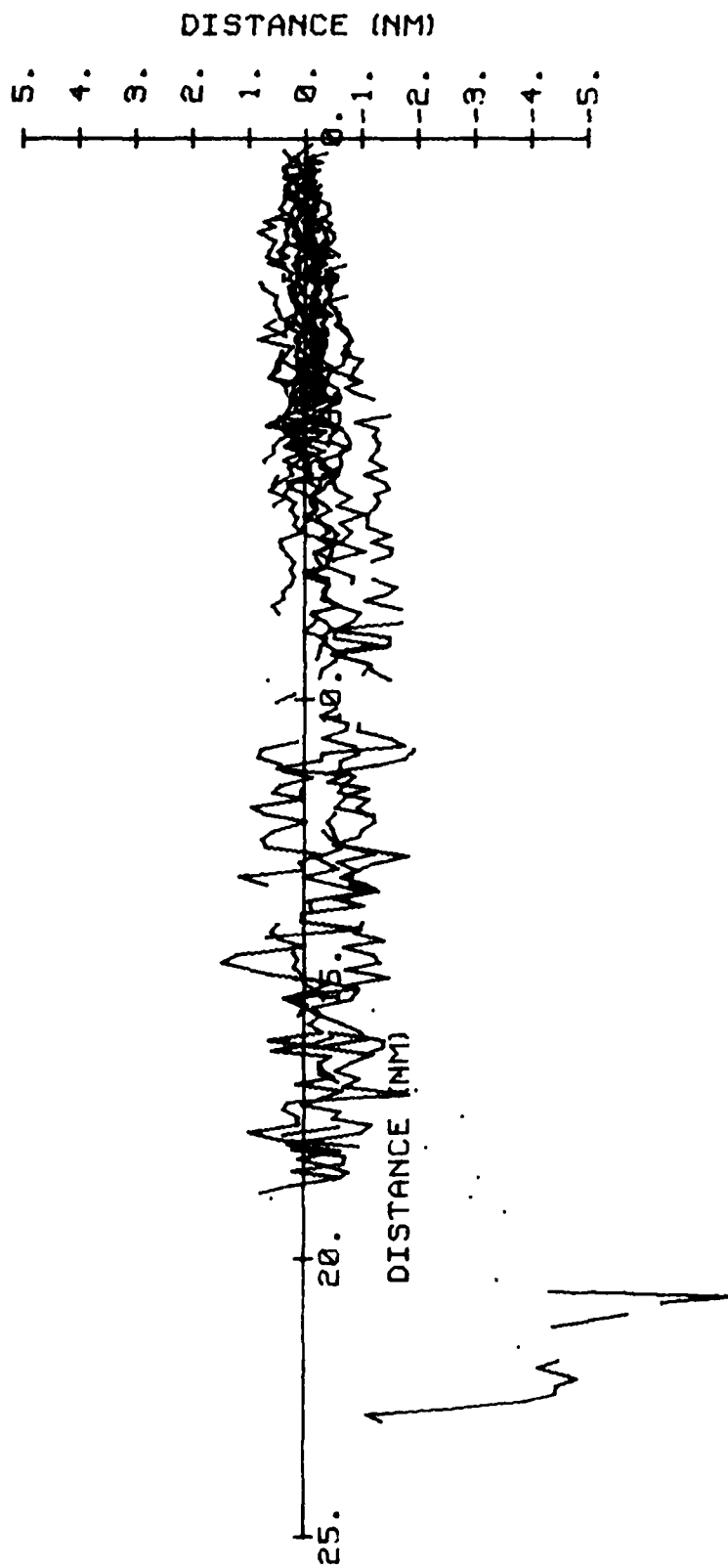


Figure 5.20 ARA Airport Single Beacon With Cursor Approach Flight Technical Error

ARA APPROACHES -- AIRPORT SITE
BENDIX RDR-1400A SINGLE BEACON MODE

11 APPROACHES
AGGREGATE FTE

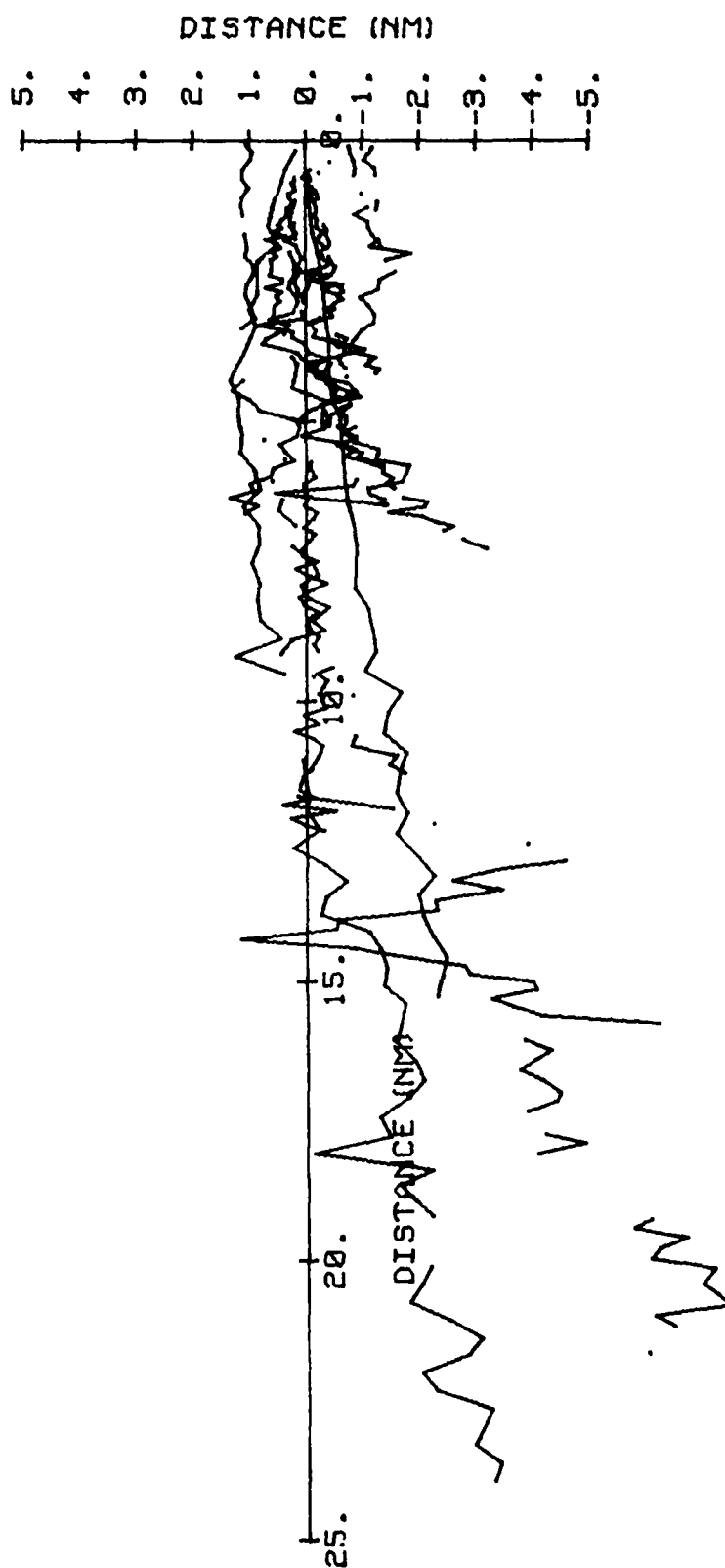


Figure 5.21 ARA Airport Single Beacon Approach Flight Technical Error

ARA APPROACHES -- AIRPORT SITE
 BENDIX RDR-1400A BEACON W/CURSOR MODE

17 APPROACHES
 AGGREGATE ASE

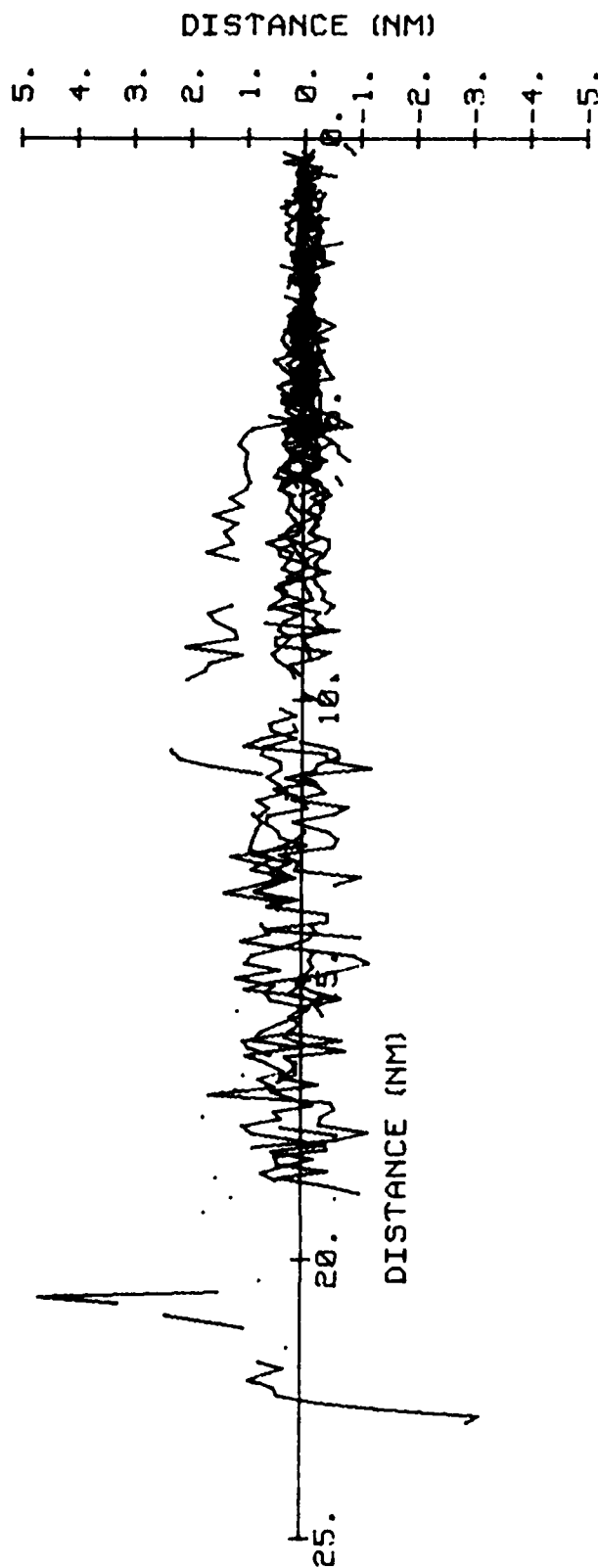


Figure 5.22 ARA Airport Single Beacon With Cursor Approach Airborne System Error

ARA APPROACHES -- AIRPORT SITE
 BENDIX RDR-1400A SINGLE BEACON MODE

11 APPROACHES
 AGGREGATE ASE

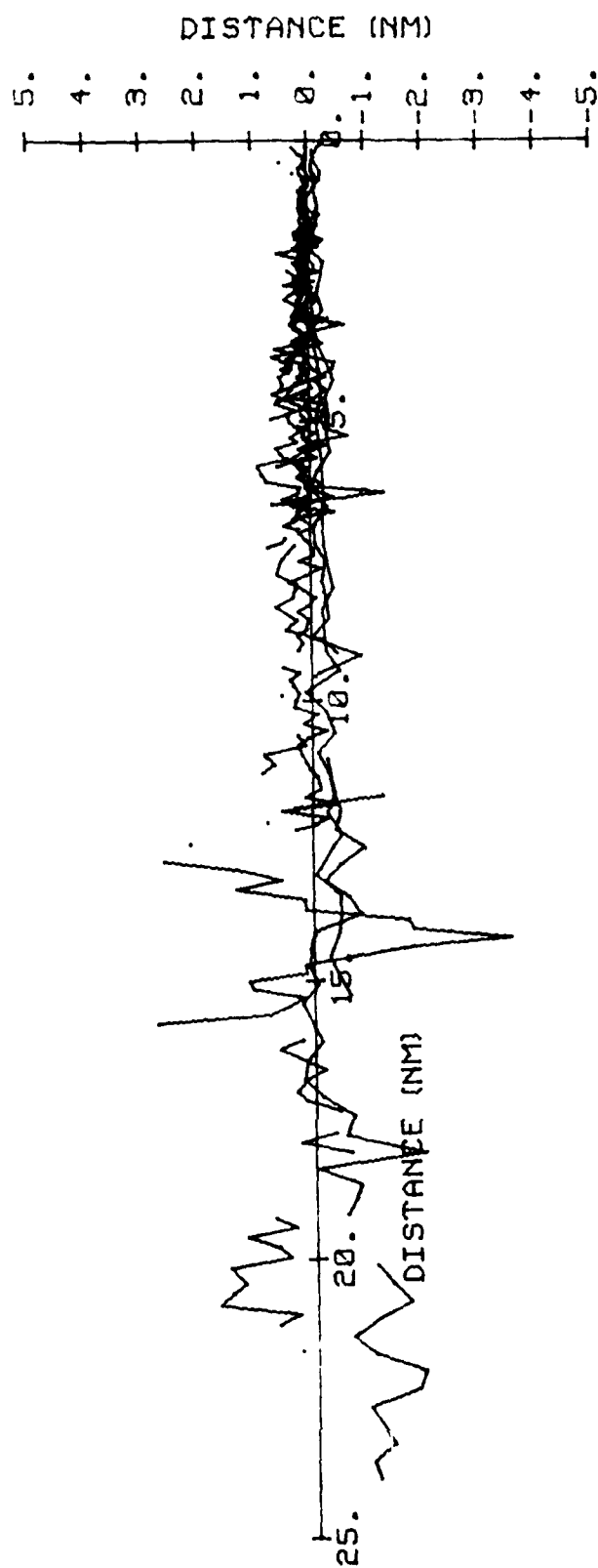


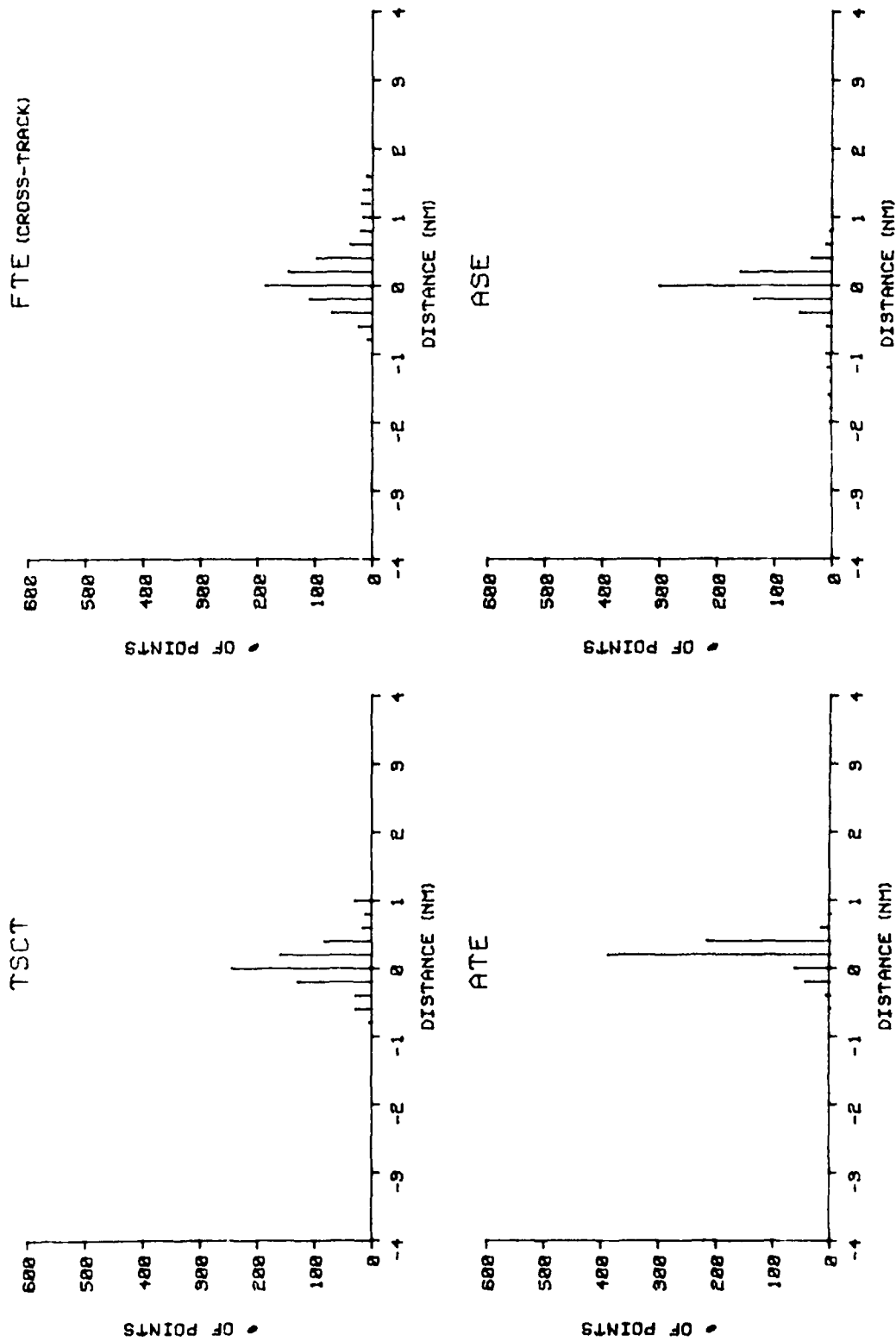
Figure 5.23 ARA Airport Single Beacon Approach Airborne System Error

Figure 5.24 presents histograms of ARA TSCT, FTE, ASE and ATE for all of the single beacon with cursor approaches flown at the airport site. Only data within ten (10) nautical miles of the beacon is included. The FTE and TSCT distributions appear almost normal although both show a slight skewness to the right. The ASE quantities appear normal while the ATE quantities appear skewed to the right. Figure 5.25 presents histograms of ARA TSCT, FTE, ASE and ATE quantities in the single beacon mode. Again the TSCT appears normal, but the FTE quantities appear skewed slightly to the right. The ASE distribution appears to be skewed to the left and the ATE distribution appears skewed to the right.

5.3.4 Airport Site: Performance Enhancement In The Beacon Mode Using The Multiple Beacon Technique

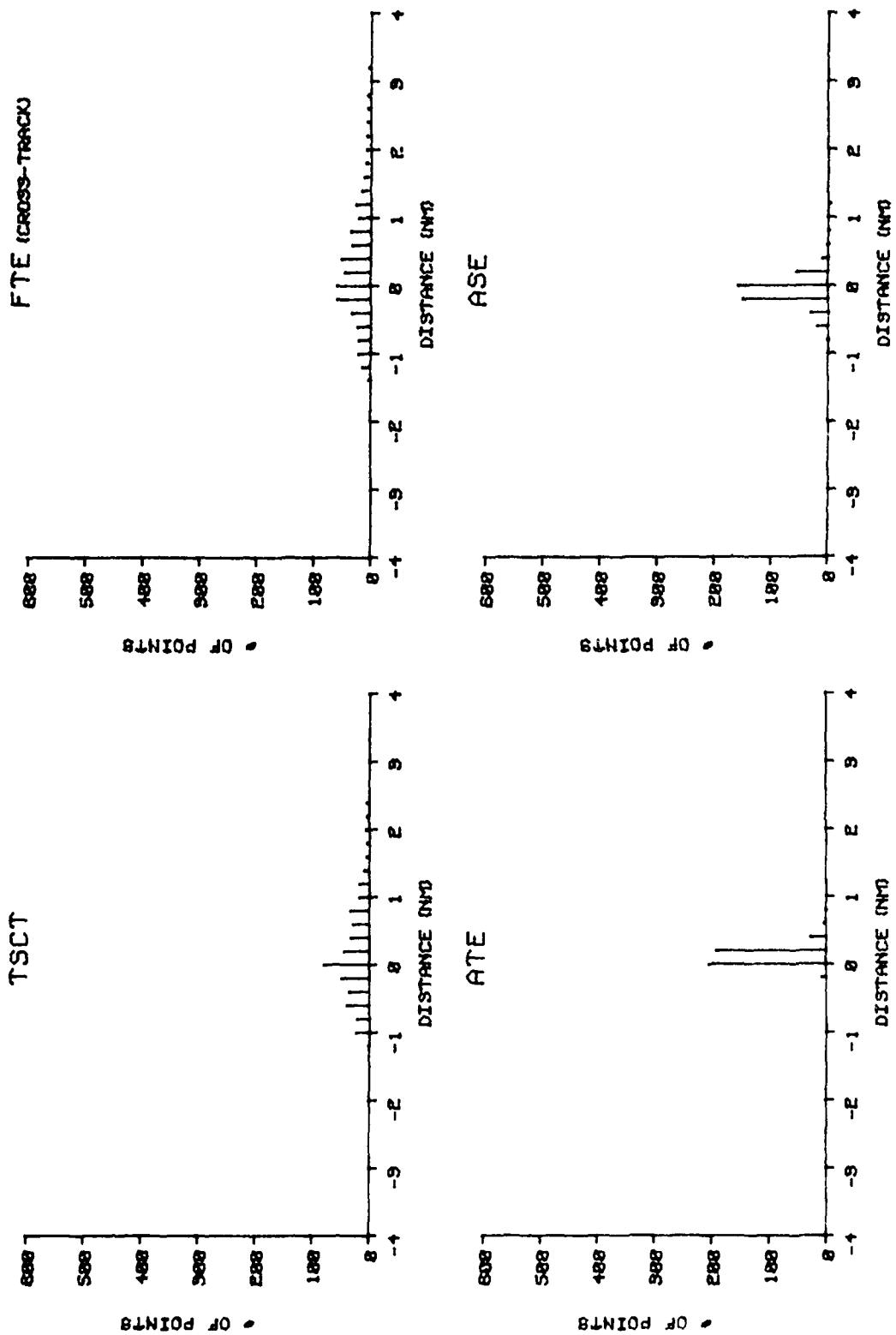
The multiple beacon testing was conducted in the NAFEC terminal area utilizing two longitudinally spaced beacons. The beacon spacing was entered as a control variable in the testing with the first or near beacon being placed on the runway threshold. The near beacon was used as the pilot's primary means of navigation while the second beacon was utilized for track orientation purposes. Although not known during the test period it was later discovered that the radar system STC was not properly adjusted. This maladjustment caused increased workload for the pilot because frequent gain adjustments were necessary and quite often the beacon return was splayed over the entire azimuth of the screen making navigation impossible. As mentioned in Section 4.2 numerous flights were flown but only those approaches where the splaying was considered to be at a minimum were recovered. Also, as mentioned earlier on two flights flown on 2 February 1979 a 3dB attenuator was utilized on the near beacon to help reduce the splaying experienced earlier in the testing. Prior to attenuation, when the gain was adjusted to make one beacon a reasonable size the other beacon became either too large in azimuth to use for navigation or disappeared completely.

Table 5.21 summarizes the results of the ARA testing conducted in the multiple beacon mode at the airport site. The statistical summary of error quantities in the table presents the mean values, standard deviations, number of data points and number of approach segments for four error quantities: ATE, ASE, FTE and TSCT. Table 5.21 shows in the ARA ATE case that the mean value is .0975 nm and the one-sigma value is



NOTE: Data Derived From 17 Approach Segments

Figure 5.24 Bendix RDR-1400A Beacon With Cursor Mode Histograms



NOTE: Data Derived From 11 Approach Segments

Figure 5.2b Bendix RDR-1400A Airport Site Single Beacon Mode Histograms

Table 5.21 NAFEC ARA Bendix RDR-1400A Multiple Beacon
Airport Approaches Error Analysis Log And
Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.0603	.1771	391	4
Short	.1163	.1154	775	11
Total	.0975	.1416	1166	15
<u>ARA ASE</u>				
Long	-.3476	.4180	391	4
Short	-.1559	.3520	775	11
Total	-.2202	.3861	1166	15
<u>FTE</u>				
Long	.1011	.9930	391	4
Short	-.0859	.4774	775	11
Total	-.0232	.6995	1166	15
<u>TSCT</u>				
Long	-.2466	.8685	391	4
Short	-.2418	.3991	775	11
Total	-.2434	.5986	1166	15
<u>IDENTIFIER</u>	<u>RWY</u>	<u>True Heading</u>	<u>Segment</u>	
1/19/79 -1	13	118	Long	
1/19/79 -2	13	118	Short	
1/19/79 -3	13	118	Short	
1/19/79 -4	13	118	Short	
2/5/79 AM-1	13	118	Long	
2/5/79 AM-2	13	118	Short	
2/5/79 AM-3	13	118	Short	
2/5/79 AM-4	13	118	Short	
2/5/79 PM-1	13	118	Long	
2/5/79 PM-2	13	118	Short	
2/5/79 PM-3	13	118	Short	
2/5/79 PM-4	13	118	Short	
8/7/79 -1	13	118	Long	
8/7/79 -2	13	118	Short	
8/7/79 -3	13	118	Short	

.1416 nm for all of the data points collected. These values correlate closely to those ATE values indicated in the airport single beacon testing (Table 5.17 - Section 5.3.3). Table 5.17 presented an ARA ATE mean of .1168 nm and a one-sigma of .1804 nm. Table 5.21 shows a mean and one-sigma value in the ASE case of -.2202 nm and .3861 nm, respectively. Table 5.17 showed a mean ARA ASE mean value of -.0554 nm and a one-sigma of .4715 nm. The multiple beacon ARA ASE values are somewhat larger than those previously seen in other test areas because of the beacon splaying encountered during the multiple beacon testing.

The Flight Technical Error (FTE) quantities indicated in Table 5.21 showed a total mean value of -.0232 nm and a one-sigma of .6995 nm. These results were obtained from a very large sample size (1166 data points). Table 5.17 showed a mean total FTE quantity of .6279 nm and a one-sigma of 1.4361 nm. These Multiple Beacon Approach quantities indicate a reduction of .6 nm in the mean value and a reduction of .74 nm in the one-sigma value. The TSCT error quantities presented in Table 5.21 showed a mean value of -.2434 nm and a one-sigma of .5986 nm. These quantities indicate a decrease of .33 nm in the mean value for all of the approach segments when compared to the single beacon quantities presented in Table 5.17.

Table 5.22 summarizes in statistical quantities the Airborne Radar Approach Multiple Beacon test data at one nautical mile intervals, starting at ten (10) nautical miles. As before the quantities are presented in both linear and angular terms. The FTE angular quantities at one nautical mile show a mean of -.21 degrees and a one-sigma of 14.2 degrees. The TSCT angular quantities at one nautical mile show a mean value of .25 degrees and a one-sigma value of 12.8 degrees. Table 5.19 (Section 5.3.3) presented the one nautical mile statistical data for the single beacon mode testing. The multiple beacon data showed a marked decrease of 23.5 degrees in the one-sigma quantity and a decrease of 4.1 degrees in the mean value. The multiple beacon linear FTE quantities in Table 5.22 show a mean value of -.0037 nm and a one-sigma of .2532 nm at one nautical mile. The one nautical mile linear TSCT quantities show a mean value of .0043 nm and a one-sigma of .2276 nm. Both TSCT and FTE means in Table 5.22 at one nautical mile are virtually zero as opposed to those TSCT and FTE means shown in Table 5.19 where the quantities indicated

Table 5.22 Bendix RDR-1400A Multiple Beacon One Nautical Mile Aggregate Data

----- LINEAR ERRORS----- Y----- ANGULAR ERRORS-----									
RM	FF	AFE	LCIT	STC	ASE	YAGI	FT2	AGE	
1	1	.1331	.0002	-.0017	.0000	.0000	-.2115	.4586	MEAN
		.0480	.0276	.2532	.0385	14.3220	14.2000	2.2613	STD
2	1	.1400	.0339	-.0196	.0210	-.1000	-.3624	-.6927	MEAN
		.0570	.2879	.2678	.0520	0.1991	0.1870	1.4972	STD
3	15	.0053	.1733	-.1002	-.0001	-.0002	-.1016	-.1095	MEAN
		.0792	.4046	.4145	.1071	7.6808	7.6659	2.0440	STD
4	12	.1927	-.2319	-.0660	-.1611	-.0007	-.9384	-.2349	MEAN
		.0940	.4066	.3919	.1232	5.8015	5.7960	2.0991	STD
5	15	.1303	-.2976	-.1264	-.1713	-.0067	-.1447	-.1048	MEAN
		.1002	.3976	.4539	.2288	4.5468	5.1874	2.6310	STD
6	15	.1189	-.3685	-.2429	-.1256	-.0519	-.1318	-.1199	MEAN
		.1362	.3849	.4507	.2312	3.6710	4.2962	2.2069	STD
7	15	.0543	-.4275	-.1988	-.2288	-.0491	-.1626	-.1071	MEAN
		.0828	.3962	.5505	.3500	3.2395	4.4962	2.6612	STD
8	15	.0810	-.4877	-.2324	-.2563	-.0480	-.1642	-.1827	MEAN
		.1217	.4194	.4516	.3740	3.0025	3.2302	2.6779	STD
9	14	.2036	-.5799	-.1717	-.4071	-.0481	-.1027	-.2013	MEAN
		.1778	.5398	.7054	.4909	1.8321	4.4818	3.1223	STD
10	9	.2121	-.6293	.0259	-.7257	-.0607	.5494	-.4150	MEAN
		.1541	.6043	.4445	.3951	3.4581	2.5450	2.2853	STD

are .07 nm and .08 nm, respectively. The FTE quantities indicated in Table 5.22 are consistently small at all range intervals out to ten (10) nautical miles. The linear multiple beacon TSCT values are also small but tend to increase as the distance from the beacon increases. For example, the linear TSCT mean value at ten (10) nautical miles is -.63 nm and the one-sigma value is .60 nm. The linear FTE and TSCT quantities indicated in Table 5.19 for the beacon only mode testing are consistently larger than those shown in Table 5.22. The ASE linear quantities presented in Table 5.22 are slightly larger than those shown in Table 5.19. For example at ten (10) nautical miles the multiple beacon ASE mean is -.73 nm and the single beacon ASE mean is -.15 nm. The ATE values indicated in Table 5.22 once again are consistently small.

Table 5.23 presents the Letdown Error (LDE) quantities for the multiple beacon testing conducted at the airport site. The LDE quantities determine the ability of the pilot to utilize the ARA system to define and identify a step-down fix. As shown earlier the LDE quantities are sampled at two approach fixes, that is the 5.0 nautical mile IAF and the 2.0 nautical mile FAF. The mean value at the IAF shows that the pilot initiated his descent .05 nm before passing the fix. The mean value at the FAF shows that the pilot initiated his descent from 500 feet to 200 feet .08 nm after passing the fix. The one-sigma values are .31 nm and .15 nm, respectively. In the multiple beacon case the pilot at the 2.0 mile fix started his decent after passing the fix as was the case in the single beacon testing.

Table 5.23 Multiple Beacon Letdown Error Quantities

Approach Position	Error Magnitudes	
	Mean nm	+1 - nm
IAF (5.0 nm Fix)	-.0460	.3130
FAF (2.0 nm Fix)	.0750	.1505

Figure 5.26 summarizes in graphical form the Total System Cross Track Error (TSCT) for the multiple beacon testing conducted at the airport site. Outside of ten (10) nautical miles the maximum deviation from intended course is 2.9 nm (at 22 nm along track distance). Between five (5) and ten (10) nautical miles the maximum deviation from the desired track is 1.5 nm and within five (5) nautical miles the maximum error indicated by Figure 5.26 is 1.1 nm. All of the approaches are flown well within the airspace requirements established by the RTCA SC-133 MOPS. Compared to Figure 5.19 (single beacon approach TSCT plot, Section 5.3.3) the approaches in Figure 5.26 at all range intervals show smaller maximum deviations from intended course. The approaches in Figure 5.26 show a marked improvement over the single beacon approaches in terms of track identification and orientation, but because of the large displayed beacon size it was still difficult to determine a course correction angle to eliminate the "homing" tendencies. Figure 5.27 presents a plot of the Flight Technical Error (FTE) quantities vs. along track distance for the multiple beacon testing conducted at the airport site. This plot can be compared to the FTE single beacon approach plot (Figure 5.21) seen in Section 5.3.3. Within five (5) nautical miles Figure 5.27 shows a maximum error quantity of 1.2 nm. In the five (5) to ten (10) nautical mile interval the maximum error shown is 3.1 nm. The larger error spikes are often due to the slow update rate of the radar in conjunction with rapid aircraft heading changes. Outside of ten (10) nautical miles the maximum error indicated by Figure 5.21 is -3.2 nm. With the exception of the one spike at nine (9) nautical miles, the FTE error quantities presented in Figure 5.27 are smaller than those presented in Figure 5.21. Although the workload during the multiple beacon approach could conceivably be higher than the single beacon approach it does seem to offer the pilot some track orientation information, therefore, reducing TSCT and FTE quantities.

Figure 5.28 is a plot of Airborne System Error (ASE) for the multiple beacon testing. As seen in all other areas of testing with the Bendix radar system the system errors are small. The plot indicates that all of the error quantities are within a ± 1.8 nm region outside of five (5) nautical miles and within a $\pm .8$ nm region within five (5) nautical miles.

ARA APPROACHES -- AIRPORT SITE
BENDIX RDR-1400A MULTIPLE BEACON MODE

15 APPROACHES
AGGREGATE TSCT

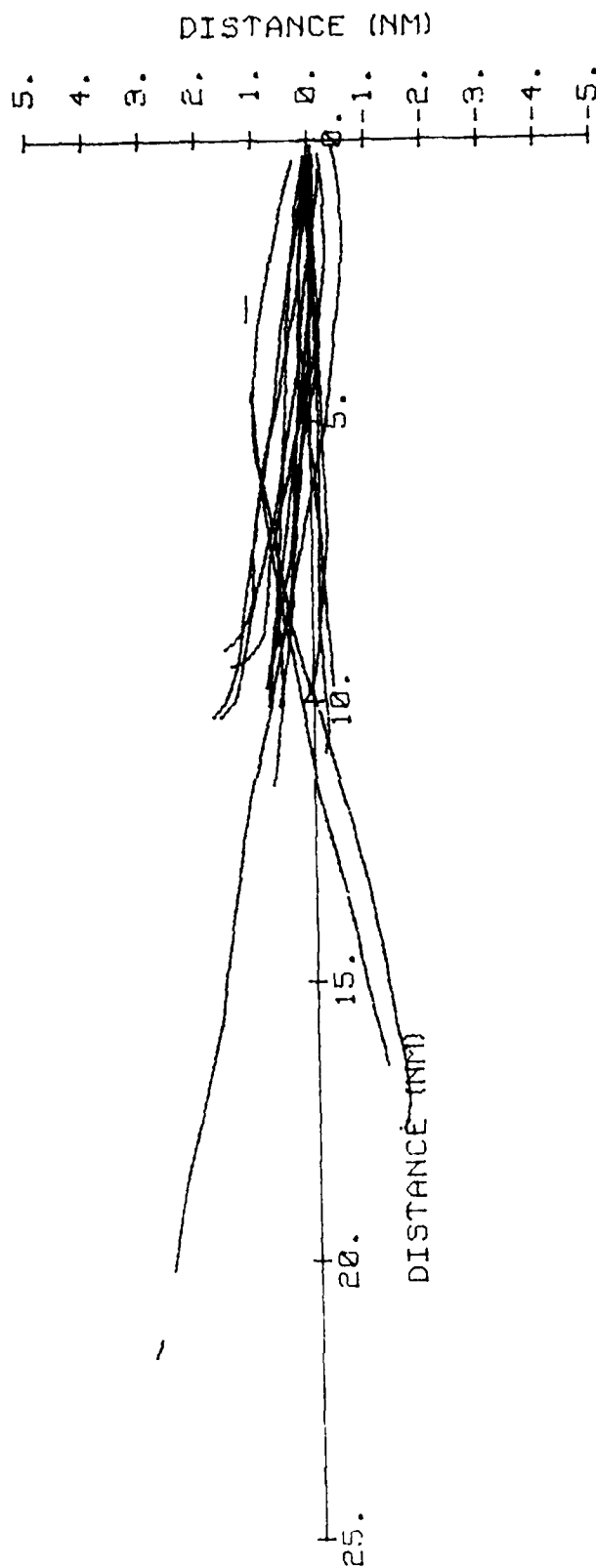


Figure 5.26 ARA Airport Multiple Beacon Mode Total System Cross Track Error

ARA APPROACHES -- AIRPORT SITE
 BENDIX RDR-1400A MULTIPLE BEACON MODE

15 APPROACHES
 AGGREGATE FTE

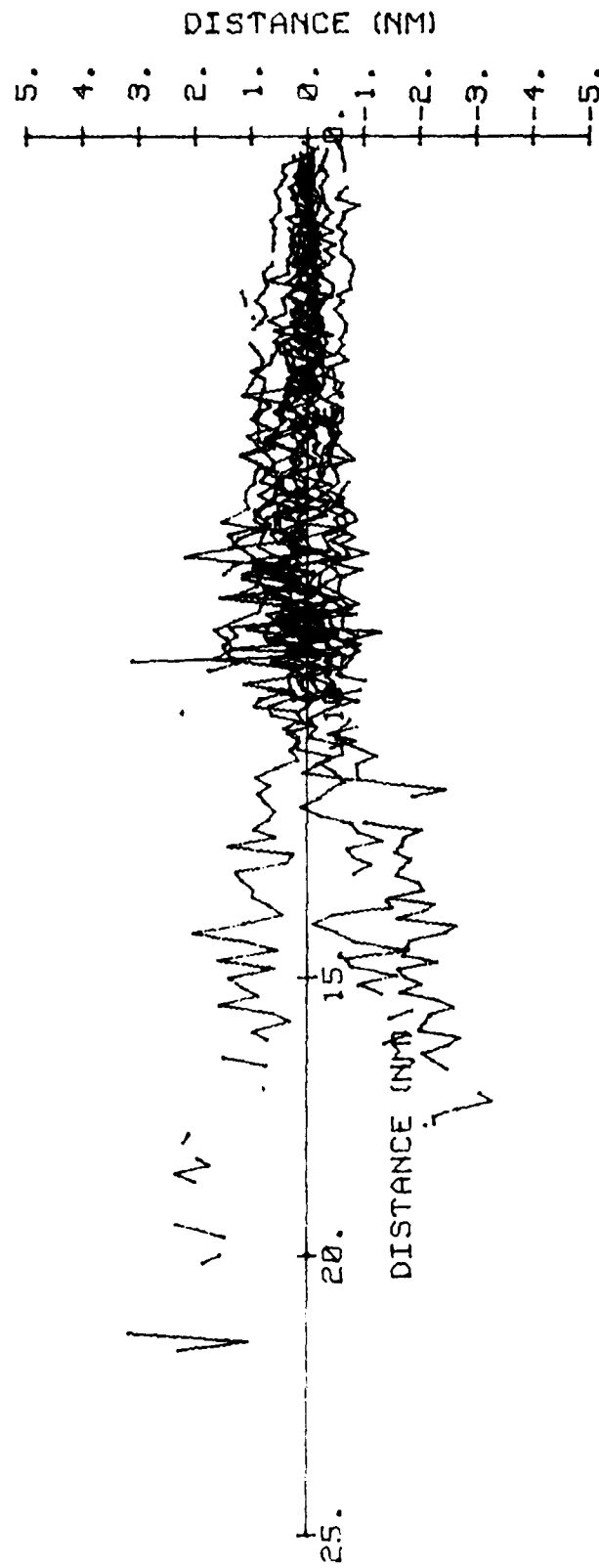


Figure 5.27 ARA Airport Multiple Beacon Mode Flight Technical Error

ARA APPROACHES -- AIRPORT SITE
BENDIX RDR-1400A MULTIPLE BEACON MODE

15 APPROACHES
AGGREGATE ASE

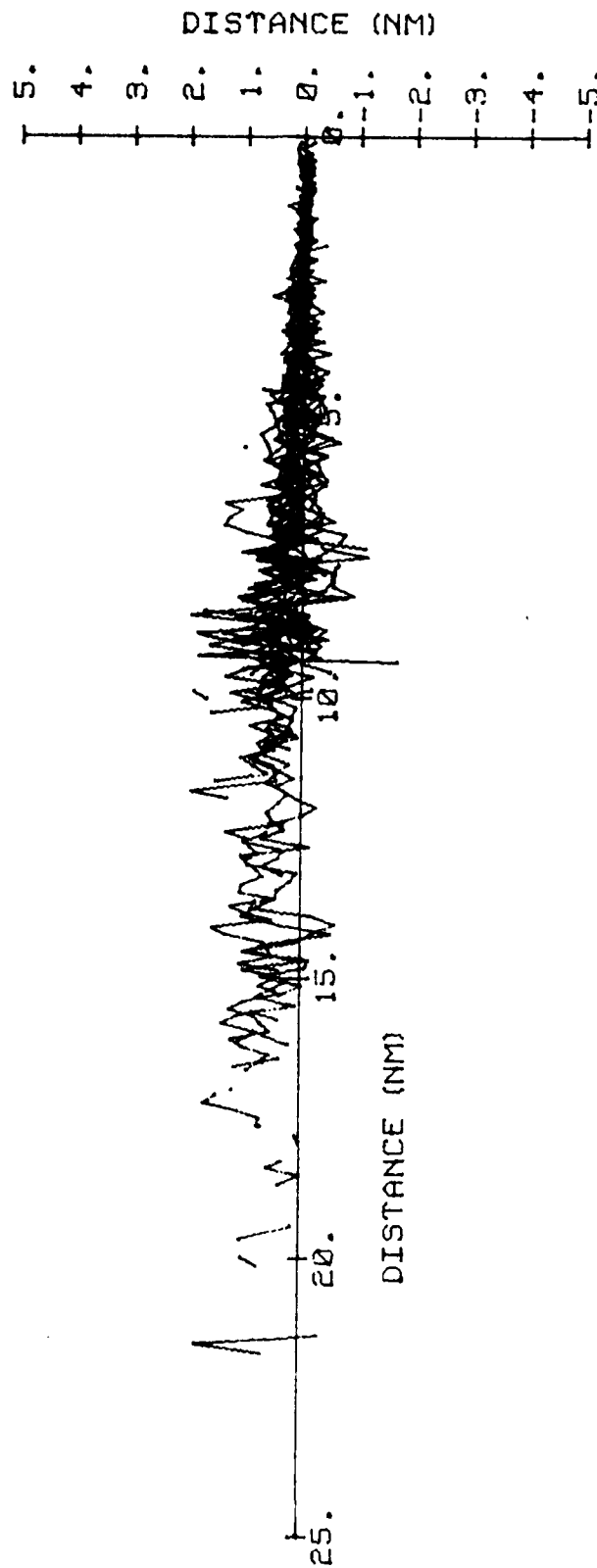


Figure 5.28 ARA Airport Multiple Beacon Mode Airborne System Error

Figure 5.29 presents histograms of the ARA TSCT, FTE, ASE and ATE quantities for the multiple beacon testing. The data is presented such that only data within ten (10) nautical miles is included. Figure 5.29 shows that the TSCT distribution appears skewed considerably to the left. The FTE distribution is skewed only slightly to the left. The system errors show that the ATE quantities are again close to zero while being skewed to the left slightly. The ASE quantities appear skewed to the left as in the TSCT and FTE cases.

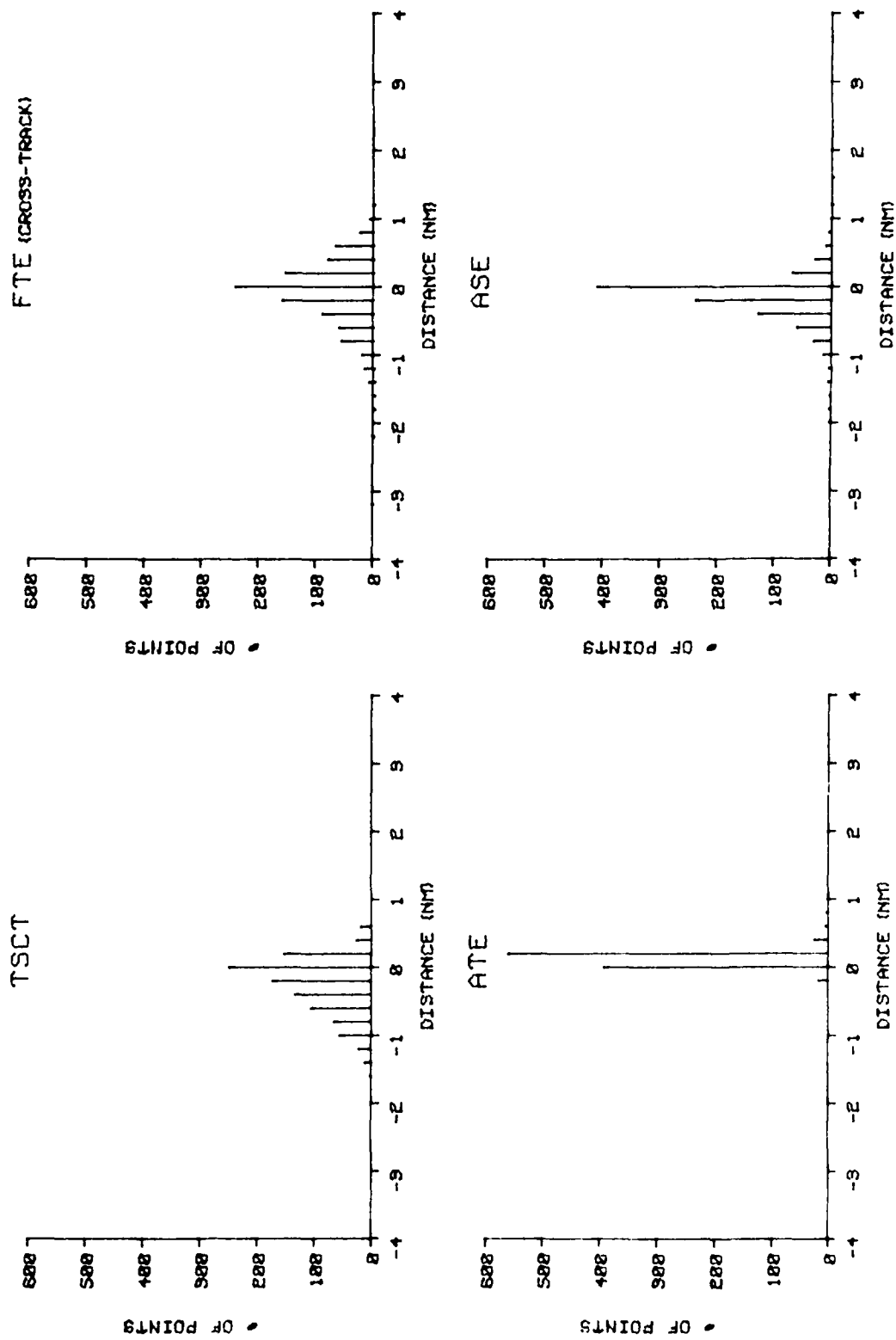
5.3.5 Offshore Site: Primus-50 Combined Mode Versus The Beacon-Only Mode

The subsection will compare the results obtained in the offshore (Brandywine Lighthouse) testing utilizing the RCA Primus-50 Radar in the combined and beacon-only modes. The combined mode offers the unique capability of interrogating a ground based transponder while at the same time displaying surrounding skin paint targets. The results are not intended to show that one mode is any better than the other in terms of accuracy, since both modes use the ground based beacon as the primary mode of navigation.

Table 5.24 summarizes the results of the ARA testing conducted at the offshore site in the combined mode. The error analysis log and statistical summary of error quantities in the table presents the mean values, standard deviations, number of data points and number of approach segments for four specific error quantities: ARA ATE, ASE, FTE and TSCT.

Table 5.24 shows in the ARA ATE case that the calculated mean is .3587 nm and the one-sigma is .2816 nm for all of the approach segments. The results for the ARA ASE were a total mean value of .1600 nm and a one-sigma value of .6360 nm. It should be noted that these results were derived for a large sample size (665 data points).

The Flight Technical Error (FTE) quantities indicated in Table 5.24 showed a mean value of -.0039 nm and a one-sigma of .6448 nm. These values were obtained from all of the approach segments flown. The TSCT values presented in Table 5.24 show a total mean value of .1561 nm and a one-sigma value of .4044 nm. The cross track values are very small in relation to the primary airspace requirements of +4 nm specified in the MOPS established by RTCA SC-133. All of the values presented in



NOTE: Data Derived From 15 Approach Segments

Figure 5.29 Bendix RDR-1400A Multiple Beacon Mode Histograms

Table 5.24 NAFEC ARA RCA Primus-50 Combined Mode
Offshore Approaches Error Analysis Log
And Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.4617	.3419	344	3
Short	.2484	.1249	321	6
Total	.3587	.2816	665	9
<u>ARA ASE</u>				
Long	.4353	.7651	344	3
Short	-.1351	.2072	321	6
Total	.1600	.6360	665	9
<u>FTE</u>				
Long	-.0327	.8396	344	3
Short	.0270	.3247	321	6
Total	-.0039	.6448	665	9
<u>TSCT</u>				
Long	.4026	.3300	344	3
Short	-.1082	.2953	321	6
Total	.1561	.4044	665	9
<u>IDENTIFIER</u>	<u>True Heading</u>		<u>Segment</u>	
6/26/79 -1	222		Short	
6/27/79 AM-1	222		Long	
6/27/79 AM-2	222		Short	
6/27/79 AM-3	222		Short	
6/27/79 PM-1	222		Long	
6/27/79 PM-2	222		Short	
6/27/79 PM-3	222		Short	
6/29/79 AM-1	222		Long	
6/29/79 AM-2	222		Short	

the table are small with the exception of the ARA ATE. This somewhat larger value is partially attributable to the large target that is displayed by the Primus-50 in the beacon and combined modes. Range interpretation is difficult on the part of the operator because of the large displayed size, but the assumption was made both operationally and in the data reduction that the return edge closest to the radar apex represented the correct range to the target. Section 5.4 will present details of the Primus-50 return size versus range setting.

Table 5.25 summarizes in statistical quantities the ARA test data at one nautical mile intervals, starting at ten (10) nautical miles in the combined mode. These quantities were calculated in both linear and angular terms. Starting at three (3) nautical miles the angular FTE quantities become large. At one nautical mile the FTE angular mean value is 6.6 degrees and the one-sigma value is 12.9 degrees. The TSCT angular quantities at one nautical mile show a mean value of 4.4 degrees and a one-sigma of 11.4 degrees. The angular TSCT two (2) and three (3) nautical mile quantities show a mean value of 3.1 and 2.6 degrees and a one-sigma of 8.8 and 8.4 degrees, respectively. The ASE angular quantities indicated in Table 5.25 are consistently small at all ranges.

The linear errors presented in Table 5.25 are very consistent and small for the entire range of the approach. The linear FTE quantities at the one nautical mile point show a mean of .12 nm and a one-sigma of .23 nm. The TSCT values (at one nautical mile) indicated in Table 5.25 show a mean value of .08 nm and a one-sigma of .20 nm. The TSCT mean value at all ranges out to ten (10) nautical miles consistently remains in the .08 nm to .21 nm interval. The ATE values are not as consistent with a mean value of .12 nm at one mile and a mean value of .34 nm at ten (10) miles.

Figure 5.30 summarizes in graphical form the total system error for all the approaches flown in the combined mode at the offshore site. The plot shows that between five (5) and ten (10) nautical miles from the beacon the maximum deviation from intended track is -1.0 nm. This quantity is well within the four (4) nautical route width established by the RTCA SC-133 MOPS. Within five (5) nautical miles the maximum deviation from the intended course is only .8 nm, which is within the required airspace limits of +1.7 nm at the MAP set by the RTCA SC-133 MOPS.

Table 5.25 RCA Primus-50 Combined Mode One Nautical Mile Aggregate Data

UM	FTE	LINEAR ERRORS				ANGULAR ERRORS			
		AGE	TSOT	FTE	ASE	TSOI	FTE	ASE	MEAN
1	1	.1177	.3765	.1151	-.0386	4.8913	1.3821	1.2112	MEAN
		.0916	.2927	.1203	.0352	11.1221	12.9577	2.0111	STD
2	2	.1026	.1076	.1862	-.0726	3.0195	3.3196	2.2511	MEAN
		.0854	.3101	.2012	.0880	5.8143	6.9610	2.1120	STD
3	3	.1213	.1397	.1743	-.0193	2.5232	3.3117	1.7511	MEAN
		.0791	.4431	.4792	.0910	3.4401	5.0749	1.0315	STD
4	4	.1211	.0727	.1971	-.0344	1.0467	1.3323	-.4708	MEAN
		.0630	.4313	.4473	.1199	6.4237	6.3890	1.7174	STD
5	5	.1247	.0377	.1934	-.1107	1.0051	2.1723	-1.2615	MEAN
		.0842	.4617	.5120	.1859	5.2755	5.8428	2.1292	STD
6	6	.2028	.1911	.2052	-.1040	.9257	1.9586	-.0935	MEAN
		.1377	.4726	.3182	.2201	1.5037	3.0359	2.1011	STD
7	7	.1325	.1040	.2174	-.1446	.8590	2.0403	-1.1911	MEAN
		.1497	.4635	.3172	.2846	3.7882	2.1933	2.8221	STD
8	8	.3117	.0869	.2101	-.1312	.6225	1.5617	1.0911	MEAN
		.0842	.4904	.5890	.4314	3.5077	4.2113	2.0017	STD
9	9	.4027	.1062	-.0003	.1003	.6376	1.0030	-.6106	MEAN
		.1139	.5388	.3036	.4519	3.4260	1.9320	1.3714	STD
10	10	.2446	.2078	.0371	.1707	1.1904	.2120	.9780	MEAN
		.1754	.5050	.4234	.6168	2.8929	2.4217	1.0238	STD

ARA APPROACHES -- OFFSHORE SITE
RCA PRIMUS-50 COMBINED MODE

9 APPROACHES
AGGREGATE TSCT

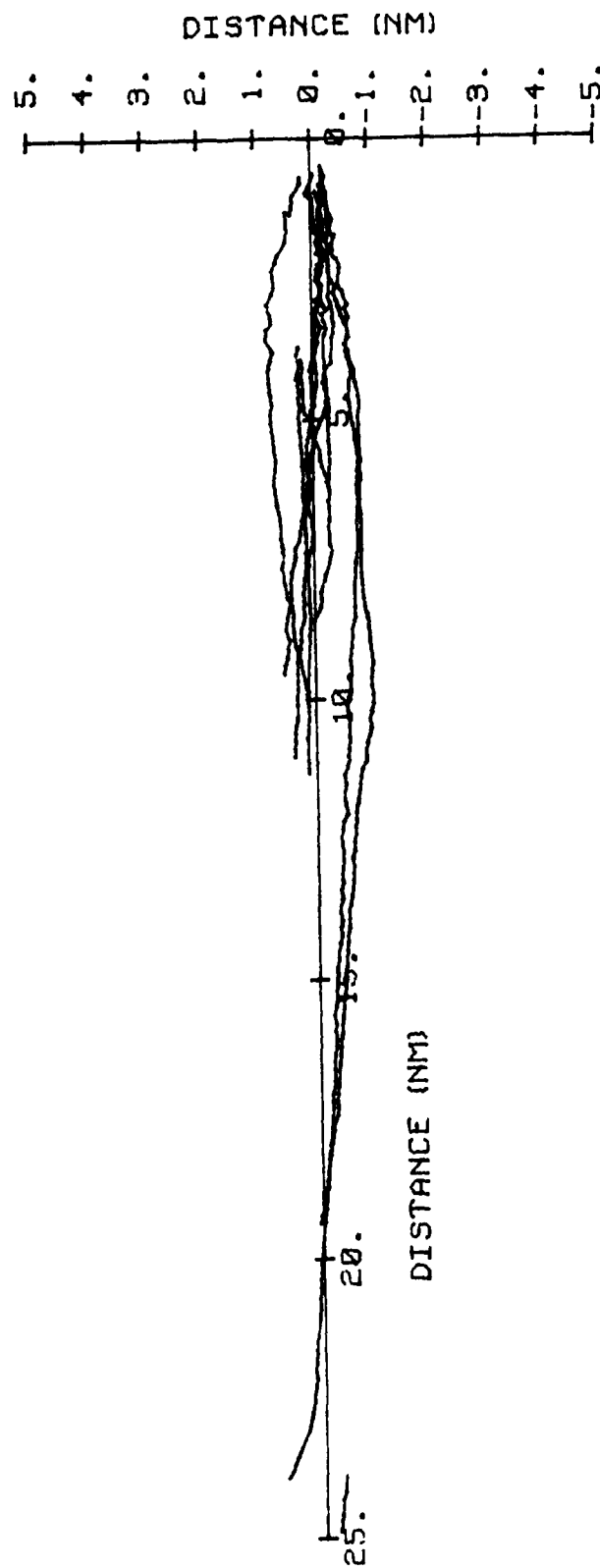


Figure 5.30 ARA Offshore RCA Primus-50 Combined Mode Total System Cross Track Error

The plot indicates that the pilot once more had a tendency to "home" towards the station, but in all cases flew directly to the target.

Figures 5.31 and 5.32 are plots of Flight Technical Error (FTE) and Airborne System Error (ASE) vs. distance along the desired track, respectively. The error quantities represent all of the approaches flown at the offshore site. Figure 5.31 shows that between ten (10) and five (5) nautical miles the maximum FTE error shown is -2.1 nm and within five (5) nautical miles the maximum error indicated is .95 nm. The maximum error indicated in Figure 5.31 is 2.5 nm at 17 nm from the beacon. Figure 5.32 shows that between ten (10) and five (5) nautical miles the maximum ASE quantity shown is -1.3 nm and within five (5) nautical miles the maximum error quantity indicated is -1.0 nm. The maximum ASE quantity indicated in Figure 5.32 is -2.8 nm at 17 nm.

Table 5.26 presents the error analysis log and statistical summary for the offshore site testing conducted in the Primus-50 beacon-only mode. Table 5.26 is identical in format to Table 5.24 and presents the same four basic error quantities. The calculated mean in the ARA ATE case shows a mean value of .3955 nm and a one-sigma of .3071 nm for all of the approach segments. The ARA ASE quantities show a mean value of -.2908 nm and a one-sigma of .4218 nm. Both of the mean and one-sigma quantities just mentioned compare favorably with those seen in the combined mode for similar error quantities.

The FTE quantities indicated in Table 5.26 show a total mean value of .5587 nm and a one-sigma of .6935 nm. The TSCT quantities presented show a mean value of .2680 nm and a one-sigma of .4231 nm. These total aggregate values are large because only one long segment approach was flown during this testing and the values indicated in Table 5.26 for the long segments are slightly larger than usual.

Table 5.27 presents the Primus-50 beacon-only mode statistical error quantities aggregated at one nautical mile intervals. As shown in Table 5.25 the quantities are presented in both linear and angular terms. The angular FTE quantities indicated in Table 5.27 at one nautical mile show a mean value of -3.4 degrees and one-sigma value of 8.6 degrees.

ARA APPROACHES -- OFFSHORE SITE
 RCA PRIMUS-50 COMBINED MODE

9 APPROACHES
 AGGREGATE FTE

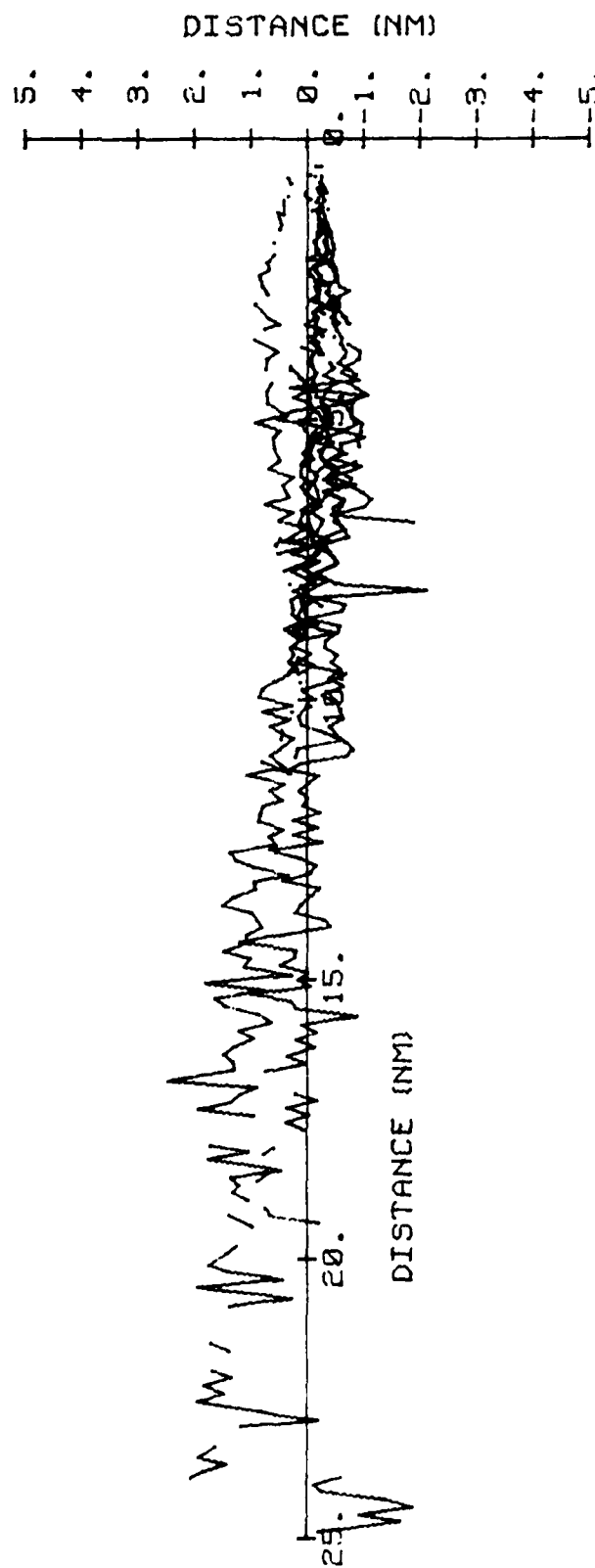


Figure 5.31 ARA Offshore RCA Primus-50 Combined Mode Flight Technical Error

ARA APPROACHES -- OFFSHORE SITE
 RCA PRIMUS-50 COMBINED MODE

9 APPROACHES
 AGGREGATE ASE

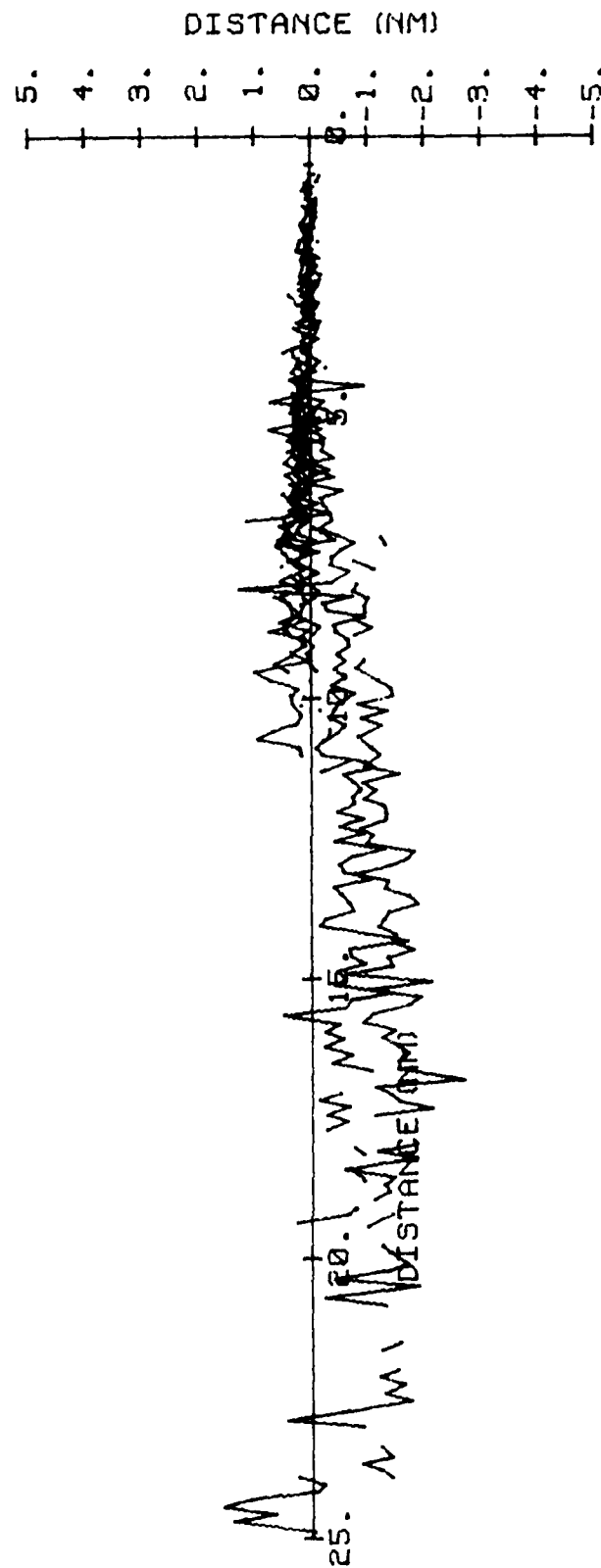


Figure 5.32 ARA Offshore RCA Primus-50 Combined Mode Airborne System Error

Table 5.26 NAFEC ARA RCA Primus-50 Beacon-Only Mode
Offshore Approaches Error Analysis Log
And Statistical Summary

	\bar{x} (nm)	σ (nm)	Data Points	Approach Segments
<u>ARA ATE</u>				
Long	.5932	.4084	173	1
Short	.2900	.1546	324	5
Total	.3955	.3071	497	6
<u>ARA ASE</u>				
Long	-.6089	.5457	173	1
Short	-.1209	.1774	324	5
Total	-.2908	.4218	497	6
<u>FTE</u>				
Long	1.2790	.6005	173	1
Short	.1741	.3468	324	5
Total	.5587	.6935	497	6
<u>TSCT</u>				
Long	.6701	.3263	173	1
Short	.0533	.2922	324	5
Total	.2680	.4231	497	6
<u>IDENTIFIER</u>	<u>True Heading</u>		<u>Segment</u>	
6/29/79 AM-3	222		Short	
6/29/79 AM-4	222		Short	
6/29/79 PM-1	222		Long	
6/29/79 PM-2	222		Short	
6/29/79 PM-3	222		Short	
6/29/79 PM-4	222		Short	

Table 5.27 RCA Primus-50 Beacon-Only Mode One Nautical Mile Aggregate Data

NM	PTS	-----LINEAR ERRORS-----				-----ANGULAR ERRORS-----			
		ATE	TOL T	FTE	ASE	TOL T	FTE	ASE	MEAN
1	4	.1000	-.0362	-.0401	.0227	-2.0703	-3.4374	1.3699	STD
2	1	.0773	.1366	.1521	.0735	4.9490	8.6489	4.2061	STD
3	5	.1713	-.1087	-.0543	-.0539	-3.1109	-1.5691	-1.5442	MEAN
4	2	.0400	.2677	.2694	.0646	8.1362	7.6707	1.8513	STD
5	7	.2174	.0036	.0885	-.0849	.0683	1.6895	-1.6203	MEAN
6	6	.0664	.4360	.4171	.0566	8.2685	7.9152	1.0818	STD
7	3	.3151	.0365	.2047	-.1182	1.2393	2.9301	-1.6927	MEAN
8	4	.0541	.4296	.4830	.1220	6.1267	6.9136	1.7469	STD
9	7	.2880	.1649	.3202	-.1552	1.8894	3.6670	-1.7793	MEAN
10	6	.0663	.3978	.4302	.1616	4.5486	4.9174	1.8806	STD
11	6	.2086	.2149	.3677	-.1523	2.0514	3.5068	-1.4386	MEAN
12	6	.0535	.3613	.3619	.1267	3.4459	3.4519	1.2098	STD
13	6	.3038	.2945	.4206	-.1261	2.4089	3.4361	-1.0313	MEAN
14	6	.0572	.3064	.3594	.1538	2.7515	2.9389	1.2035	STD
15	6	.3106	.3335	.3744	-.2389	2.4017	4.1070	-1.7103	MEAN
16	4	.0677	.3228	.4532	.2038	2.8106	3.2425	1.4593	STD
17	4	.7245	.3399	.5531	-.2122	2.1627	3.5166	-1.3570	MEAN
18	4	.3291	.4310	.4315	.0355	2.7420	2.7447	.2262	STD
19	1	.0000	.0000	.0000	.0000	.0000	.0000	.0000	MEAN
20	1	.0000	.0000	.0000	.0000	.0000	.0000	.0000	STD

The TSCT angular quantities at one nautical mile show a mean value of -2.1 degrees and a one-sigma of 4.9 degrees. All of the quantities indicated at ten (10) miles are zero because there was only one data point available in this interval. The FTE linear quantities presented in Table 5.27 show a mean value of -.06 nm and a one-sigma of .15 nm at the one nautical mile point. The largest FTE quantities can be seen at the eight (8) nautical mile point where the mean and one-sigma values are .57 nm and .45 nm, respectively. The same can be seen for the linear TSCT values at the eight (8) nautical mile point where the mean is .34 nm and the one-sigma is .32 nm. The ATE and ASE linear quantities increase progressively as the distance from the beacon increases.

Figure 5.33 is a plot of total system error of all the approaches flown at the offshore site in the Primus-50 beacon-only mode. The long approach represented in this plot verifies a point made earlier in this subsection. The approach shows that without the aid of some type of track orientation technique the pilot has a tendency to "home" to the station. Outside of ten (10) nautical miles the maximum deviation from intended course is -1.1 nm. Between ten (10) and five (5) nautical miles the maximum quantity is -1.0 nm and within five (5) nautical miles the largest error shown is .6 nm.

Figures 5.34 and 5.35 are graphical representations of FTE and ASE, respectively, for all the approaches flown in the Primus-50 beacon-only mode. The FTE and ASE values are plotted vs. along track distance to the target. The FTE plot shows a maximum error quantity of -2.5 nm outside of ten (10) nautical miles. Within ten (10) nautical miles the maximum error shown is -1.4 nm (at seven (7) nautical miles). The ASE quantities from Figure 5.35 show a maximum error of .8 nm within ten (10) nautical miles and the largest error shown is -2.1 nm (at 22.5 nm along track distance). All of the FTE and ASE values in Figures 5.34 and 5.35 are very small which reflects good system quality and good approach procedures.

Figures 5.36 and 5.37 are histograms of ARA TSCT, FTE, ASE, and ATE for the RCA Primus-50 combined and beacon-only modes, respectively. The TSCT distribution presented in Figure 5.36 appears skewed to the left, while the FTE distribution appears normal. The radar system errors presented in Figure 5.36 shows that the ATE distribution appears skewed slightly to the

ARA APPROACHES -- OFFSHORE SITE
 RCA PRIMUS-50 BEACON-ONLY MODE

6 APPROACHES
 AGGREGATE TSCT

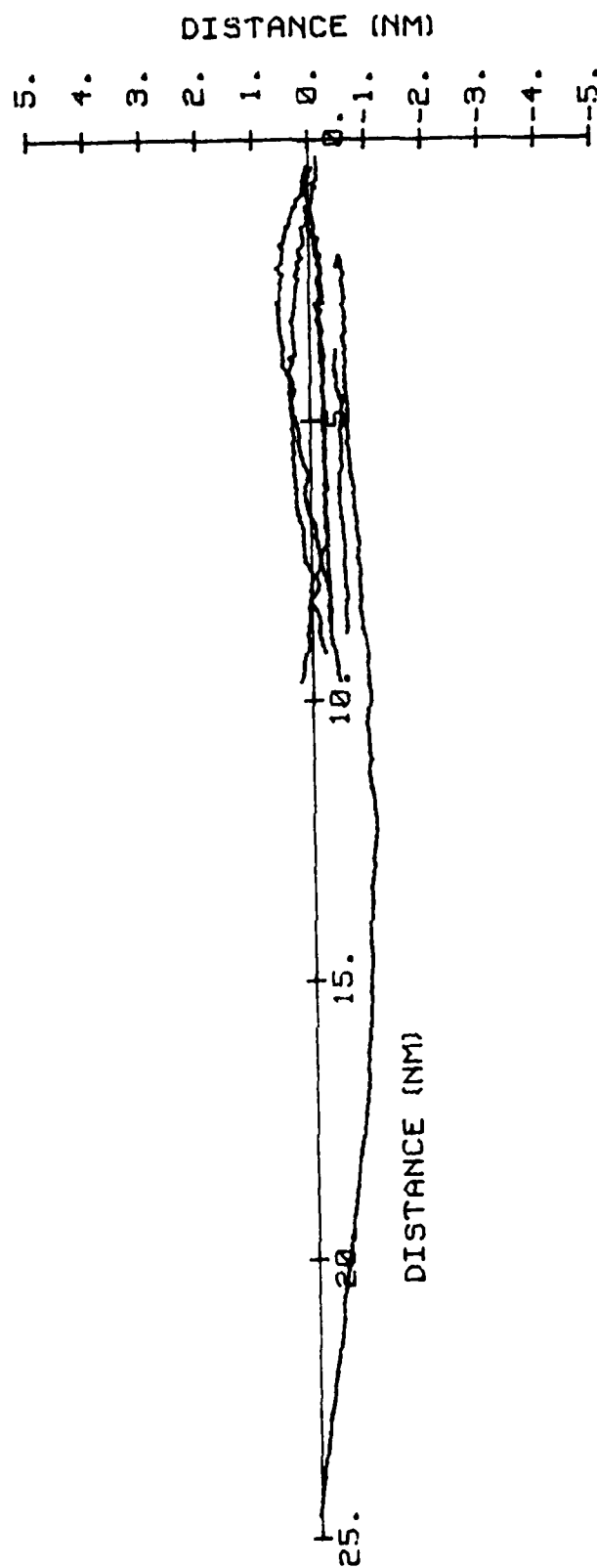


Figure 5.33 ARA Offshore RCA Primus-50 Beacon-Only Mode Total System Cross Track Error

ARA APPROACHES -- OFFSHORE SITE
RCA PRIMUS-50 BEACON-ONLY MODE

6 APPROACHES
AGGREGATE FTE

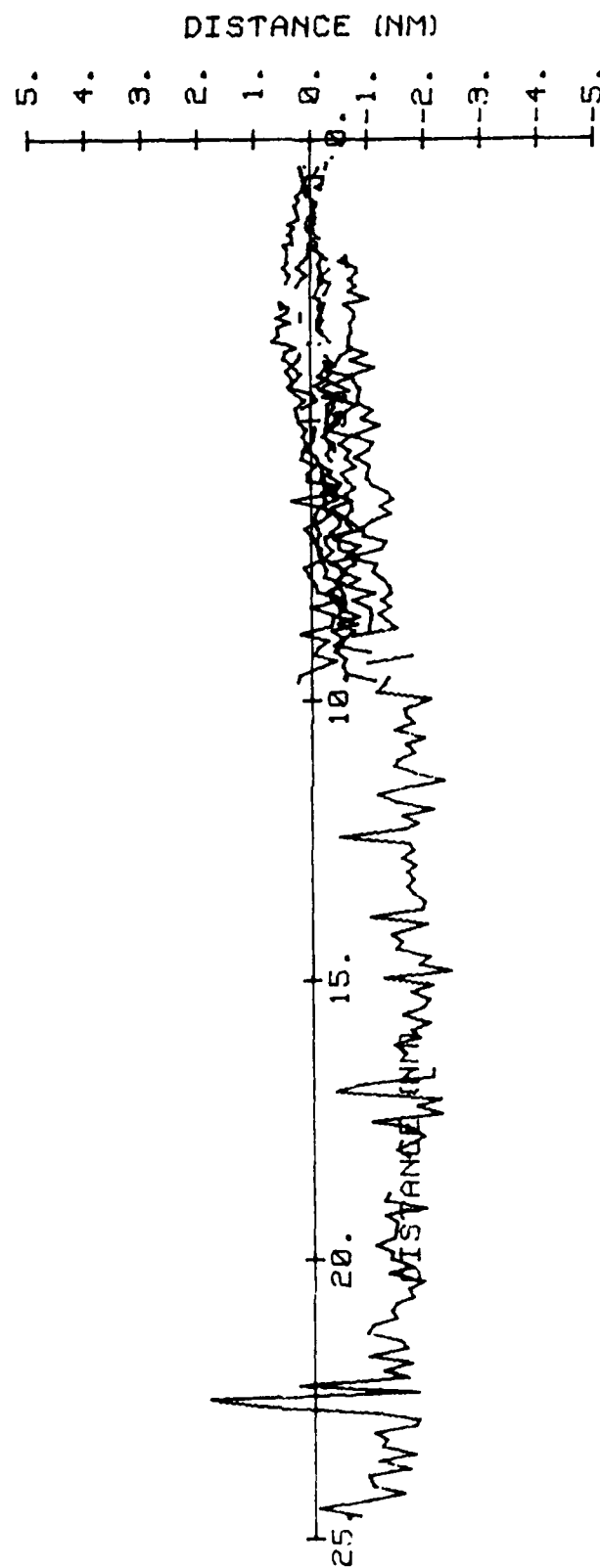


Figure 5.34 ARA Offshore RCA Primus-50 Beacon-Only Mode Flight Technical Error

ARA APPROACHES -- OFFSHORE SITE
RCA PRIMUS-50 BEACON-ONLY MODE

6 APPROACHES
AGGREGATE ASE

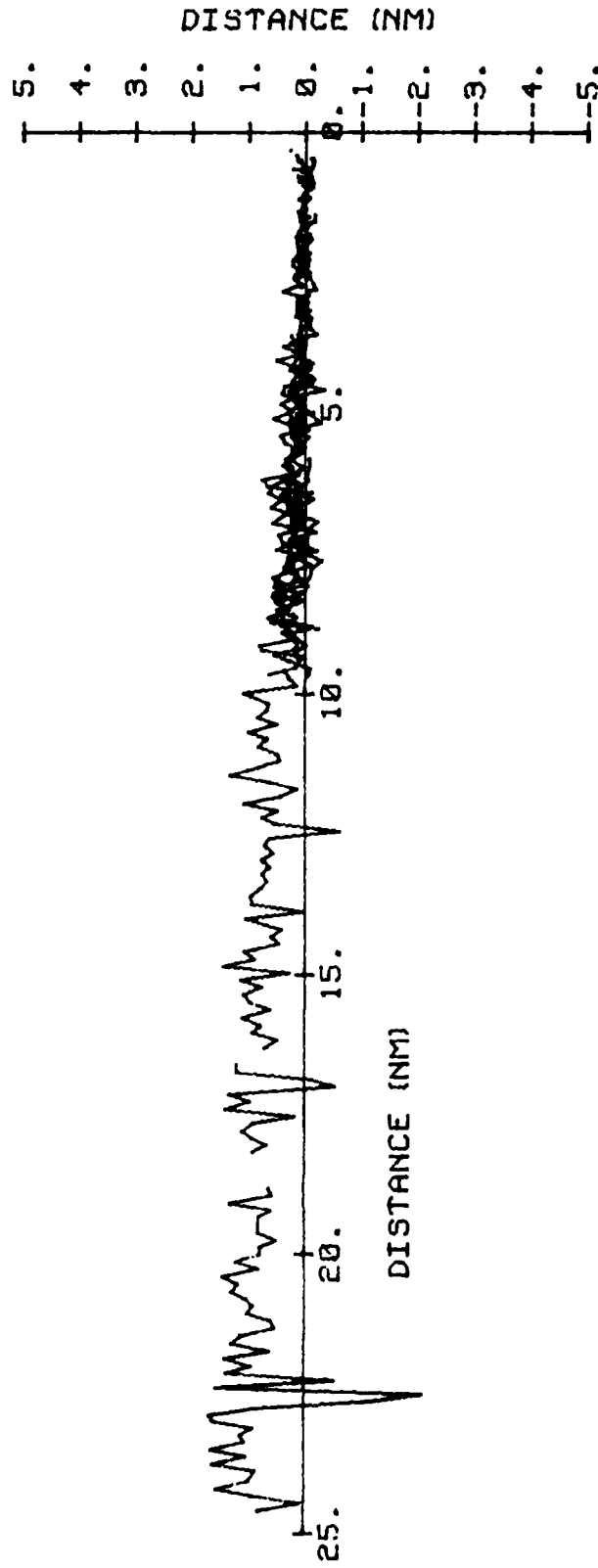
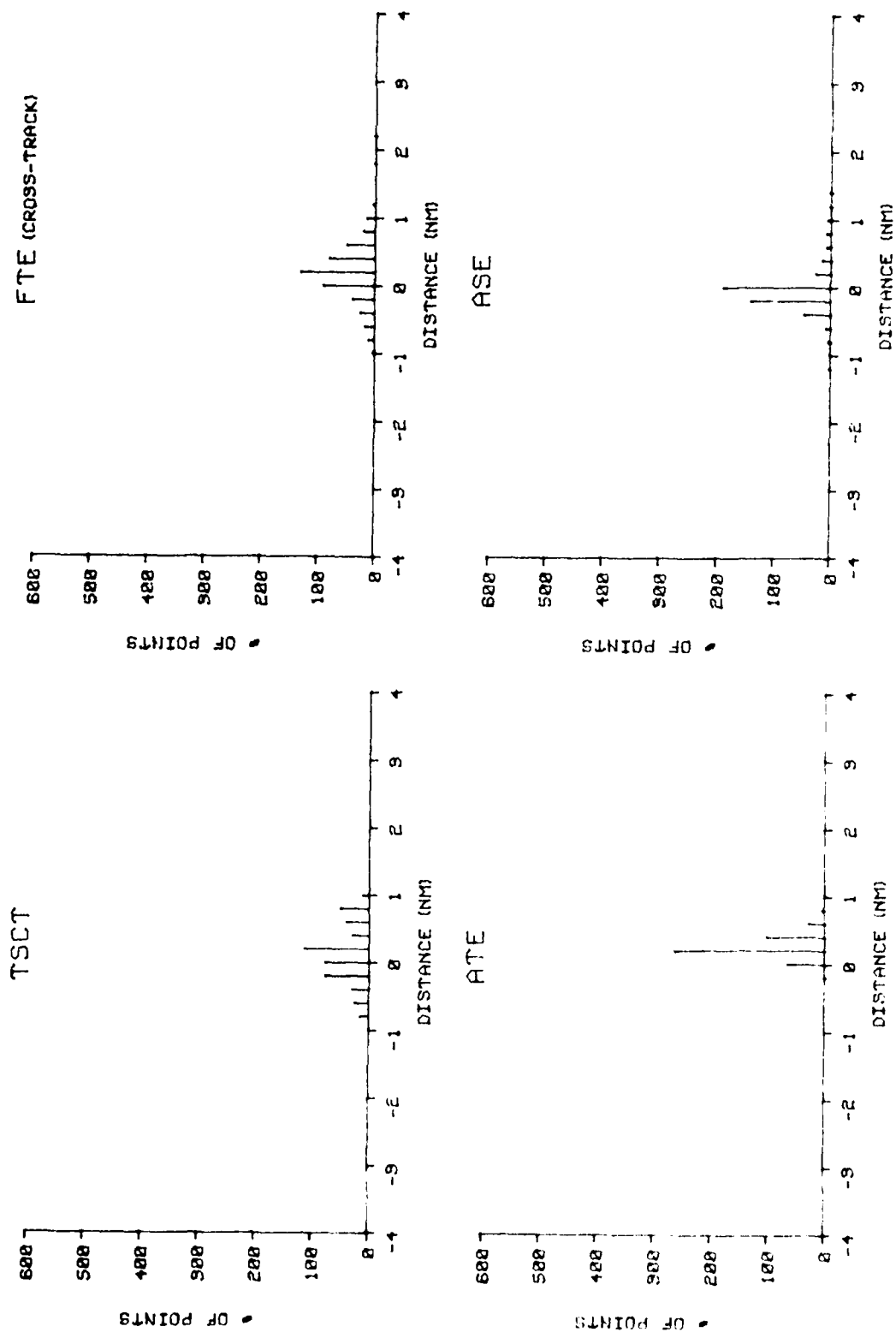
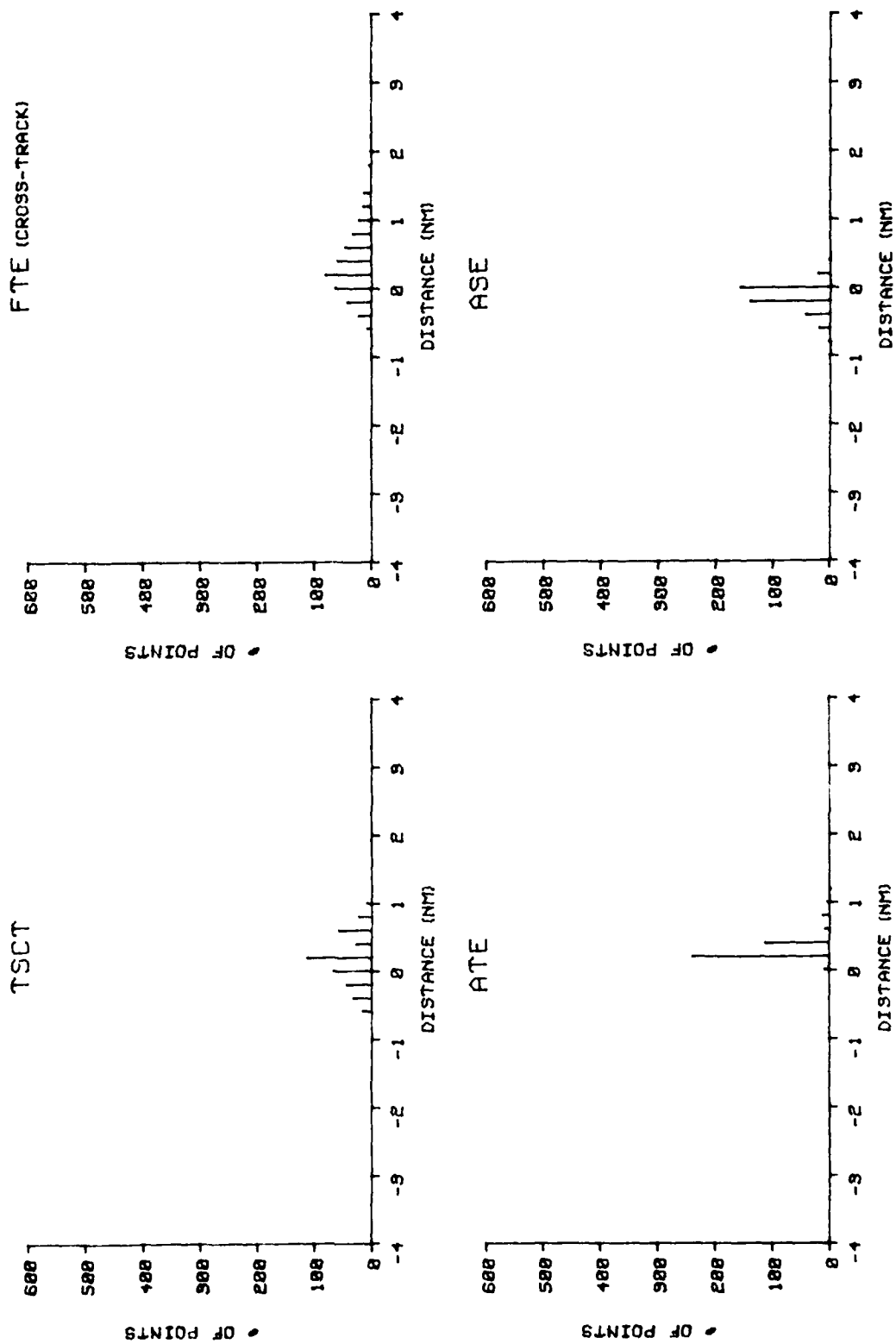


Figure 5.35 ARA Offshore RCA Primus-50 Beacon-Only Mode Airborne System Error



NOTE: Data Derived From 9 Approach Segments

Figure 5.36 RCA Primus-50 Combined Mode Histograms



NOTE: Data Derived From 6 Approach Segments

Figure 5.37 RCA Primus-50 Beacon-Only Mode Histograms

right and the ASE distribution appears skewed to the left. The TSCT and FTE quantities presented in Figure 5.37 appear skewed to the right while the ATE distribution is also skewed to the right and the ASE quantities appear skewed to the left.

The data presented in this subsection (5.3) indicated that the track orientation techniques utilized enhanced the overall ARA performance. The cursor technique afforded the pilot with better course guidance therefore, reducing the FTE and TSCT quantities. The cursor technique proved effective in both the skin paint and beacon modes. The multiple beacon technique also showed a decrease in the FTE and TSCT quantities in comparison to the single beacon testing. The RCA Primus-50 testing showed that in the combined mode because of the large displayed beacon size close-in surrounding skin paint targets were blocked out. An operational evaluation will be discussed in Section 5.4 and the results will be further discussed in Section 6.0, Summary of ARA Performance.

5.4 OPERATIONAL EVALUATION OF THE ARA CONCEPT

Operationally the Airborne Radar Approach (ARA) concept is a practical solution to navigation where conventional navigation aids are unavailable. There are certain areas though that need careful consideration which relate to the operational feasibility of the Airborne Radar Approach System utilizing various track orientation techniques. First, the ground based beacon transponders must have an effective backup system. At times during this phase of testing and during the single beacon approach testing the beacons were either inoperative or weak and intermittent. This particular problem caused serious problems especially during the multiple beacon testing because without some means of beacon identification, if one beacon is inoperative it is impossible to determine whether or not the displayed beacon is the intended target. Second, the Airborne System needs to offer more advanced features to reduce the pilot's workload. The copilot must constantly monitor the gain (especially in the multiple beacon mode), tilt, range controls and aircraft heading. For purposes of reducing crew workload more advanced Sensitivity Time Constant (STC) circuitry in the Airborne Radar System or variable-gain beacons are required. It should be noted that the STC was not properly adjusted in the Bendix Radar System during the multiple beacon testing.

This fact was verified by the Bendix Corporation (and an adjustment was made) before the start of the skin paint, skin paint with cursor and single beacon with cursor testing. Also, the pilot needs some indication of the aircraft's actual deviation from intended course. This information was supplied to the pilot by utilizing the cursor technique and the multiple beacon technique. It was the purpose of these tests to determine if by using these track orientation techniques the pilot could fly the intended course more accurately with a reduction in mental workload.

The Airborne System Error quantities presented in Section 5.3 indicate that the present "State-of-the-art" system is capable of accurate navigation. The operational problems as related to airspace lie in two areas: pilot's workload and pilot's interpretation of the information presented by the radar system. This presentation of information might include a beacon return, a skin paint return, multiple beacon returns or a beacon with cursor return. Certainly training and workload correlate closely together. If the pilot is trained well and understands the concepts involved in flying the approach, the workload is reduced. It is certainly obvious that even a trained pilot should not have to be constantly changing display controls, since this only distracts from his primary duty of flying the approach safely. Presently the Airborne Radar System return display is adequate, but improvements could be made. For example the wide target azimuth displayed by the Bendix Radar could be improved upon. Also, the large return (both in range and azimuth) displayed in the beacon only and combined modes by the Primus-50 radar certainly could be improved. The cursor technique implemented by NAFEC on the Bendix System certainly is a major improvement in displayed track orientation information. The cursor aided approaches as shown earlier in Section 5.3 required less airspace than the non-cursor approaches. The marked reduction in the FTE and TSCT values is significant.

5.4.1 Landside ATC Integration

Landside ATC integration could offer some interesting problems because of the items discussed in Section 5.1.3. Although the Airborne System accuracy is good, some difficulties exist in integrating Airborne Radar Approaches into the present ATC System. Comparatively speaking, a standard NDB approach is the present day non-precision approach equivalent

to an ARA. With the implementation of the cursor technique it is feasible to say that the radar offers a weak form of omnidirectional guidance capability. This extra course guidance available with the cursor technique positively impacts airspace requirements. As with any non-precision approach the pilot's proficiency will directly impact the overall accuracy of the approach.

As shown in Section 5.3, the figures indicate that a ± 4 nm route width, as established by RTCA SC-133, will be required for those approaches that do not utilize any type of track orientation techniques. Figures presented later in this section relating to airspace requirements will show that those approaches that utilized track orientation techniques used considerably less airspace. If an Airborne Radar Approach to a helipad requires considerable airspace, then the controller will surely need to consider this fact when vectoring other aircraft in his area, because this will surely affect the controller's position in assuring safety to aircraft in this area. The impact of this could potentially be delays in terminal operations. Airborne Radar Approach procedures also need to offer sufficient obstacle clearance, depending on the overall accuracy of the system. If this is the case then ARA altitude minimums might possibly have to be raised above those of the present day non-precision approaches.

The procedures utilized for ARA should also consider that, when making an Airborne Radar Approach, positive navigation is only available when flying to the target. This positive navigation might also necessitate the use of beacons instead of depending strictly on skin paint. This could possibly require that some other navigational aid be used to initially acquire the intended inbound track. At NAFEC, during the test program RNAV was used for initial course acquisition. Results show that the inaccuracy of the RNAV system used offered some poor course acquisition techniques in the terminal area especially during the single beacon testing (Reference 1). This presents another problem to the controller. The controller must then consider that the pilot will be using two operationally different navigational aids to fly the approach, both having different accuracies and different procedures necessary to make the approach successful. The landside integration of Airborne Radar

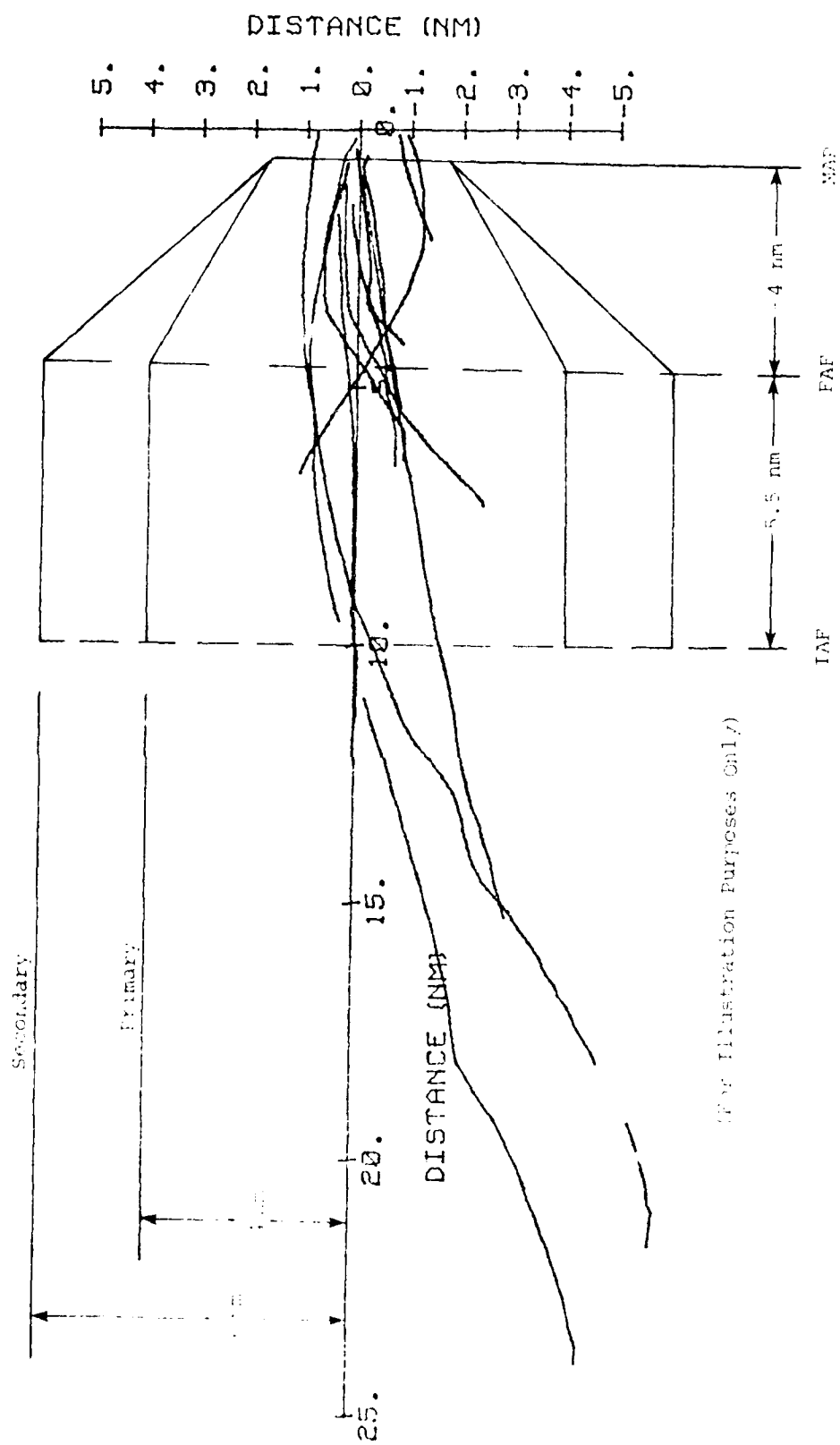
Approaches could present difficulties at first, but in time, when standard procedures are developed and airborne system features are improved, airborne radar could possibly become an integral part of our terminal navigation system.

5.4.1.1 Airport Terminal Area

The airport site is without question the most important area in which to consider the ATC integration impact. The airport environment could produce many traffic and obstacle hazards not found at offshore sites. In an environment such as this, many considerations must be recognized so that the procedures utilized offer the utmost safety. A major consideration is the airspace required to repeatably fly an Airborne Radar Approach down to established minimums successfully. This subsection will present plots of mean, mean ± 2 -sigma values for four specific error quantities: TSCT, FTE, ASE and ATE.* Also plots of TSCT quantities will be presented with the airspace boundaries established by RTCA SC-133 overlaid.

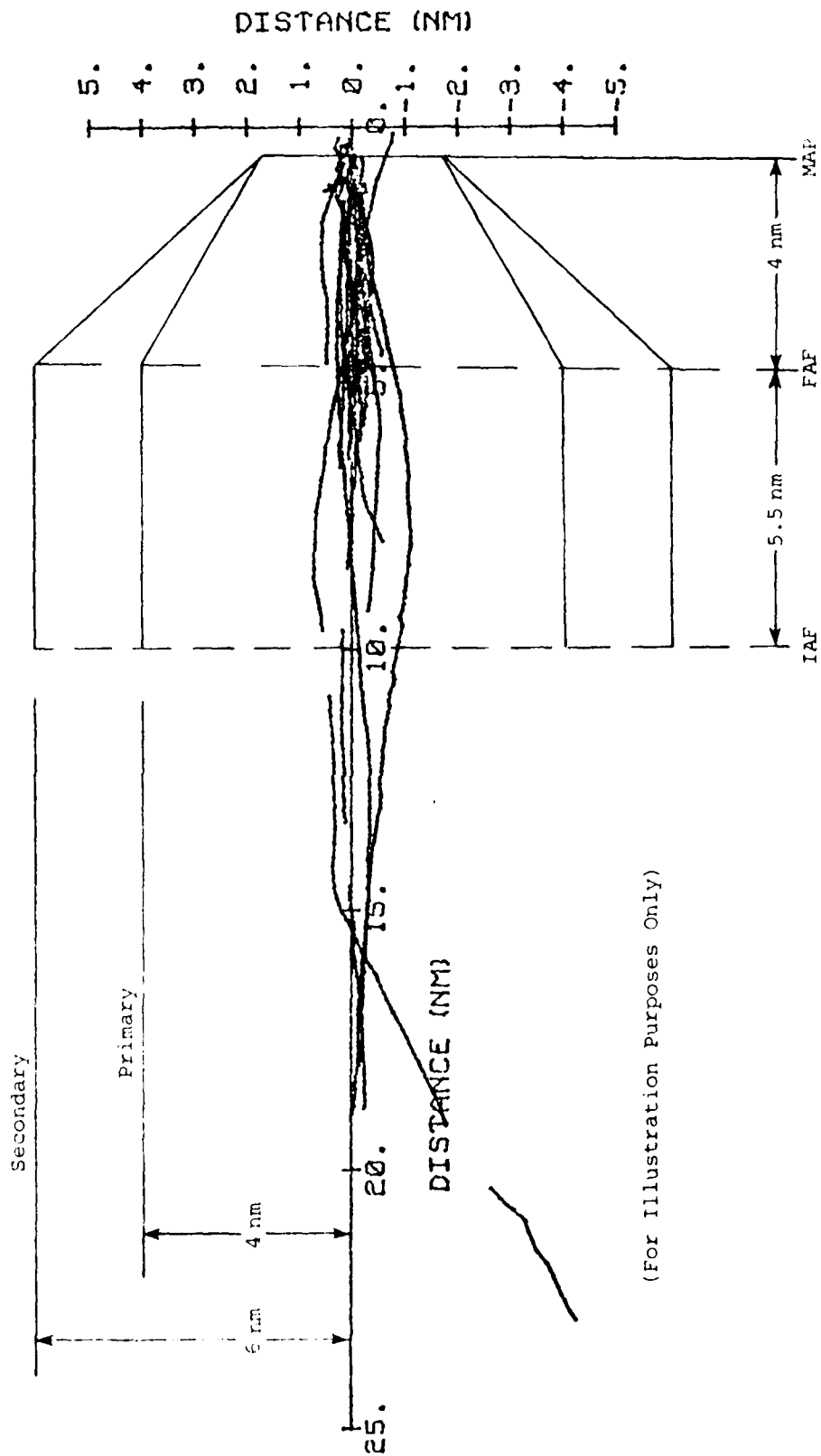
Figures 5.38 - 5.40 present a graphical representation of the airport approaches as they relate to obstacle clearance airspace for three specific test areas: single beacon-only, single beacon with cursor and multiple beacon, respectively. The primary and secondary airspace requirements shown are those indicated in the Minimum Operational Performance Standards (MOPS) established by RTCA SC-133. The Initial Approach Fix (IAF) and Final Approach Fix (FAF) shown in Figures 5.38 - 5.40 are not the same IAF and FAF used in the testing procedures. These approach fixes are the recommended approach fixes established by RTCA SC-133. Figure 5.38 shows that for the ARA single beacon approach testing from the IAF to the MAP all of the approaches lie within the primary airspace requirements. Figure 5.39 shows that for the ARA single beacon with cursor approaches, again from the IAF to the MAP, all of the approaches lie within the primary boundaries but a comparison between Figures 5.38 and 5.39 will show that the cursor aided approaches were flown with a great deal more precision. In fact, all of the cursor aided approaches lie within ± 4.0 nm requirement. Figure 5.40 presents an airspace requirement plot for the multiple beacon testing conducted at the airport site. These approaches also lie within the primary airspace boundaries from the IAF to the MAP.

/NOTE/ *These plots were generated utilizing aggregate data at one nautical mile intervals.



(For Illustration Purposes Only)

Figure 5.38 APA Airport Single Beacon Approaches Related To Obstacle Clearance Airspace



(For Illustration Purposes Only)

Figure 5.39 ARA Airport Single Beacon With Cursor Approaches Related To Obstacle Clearance Airspace

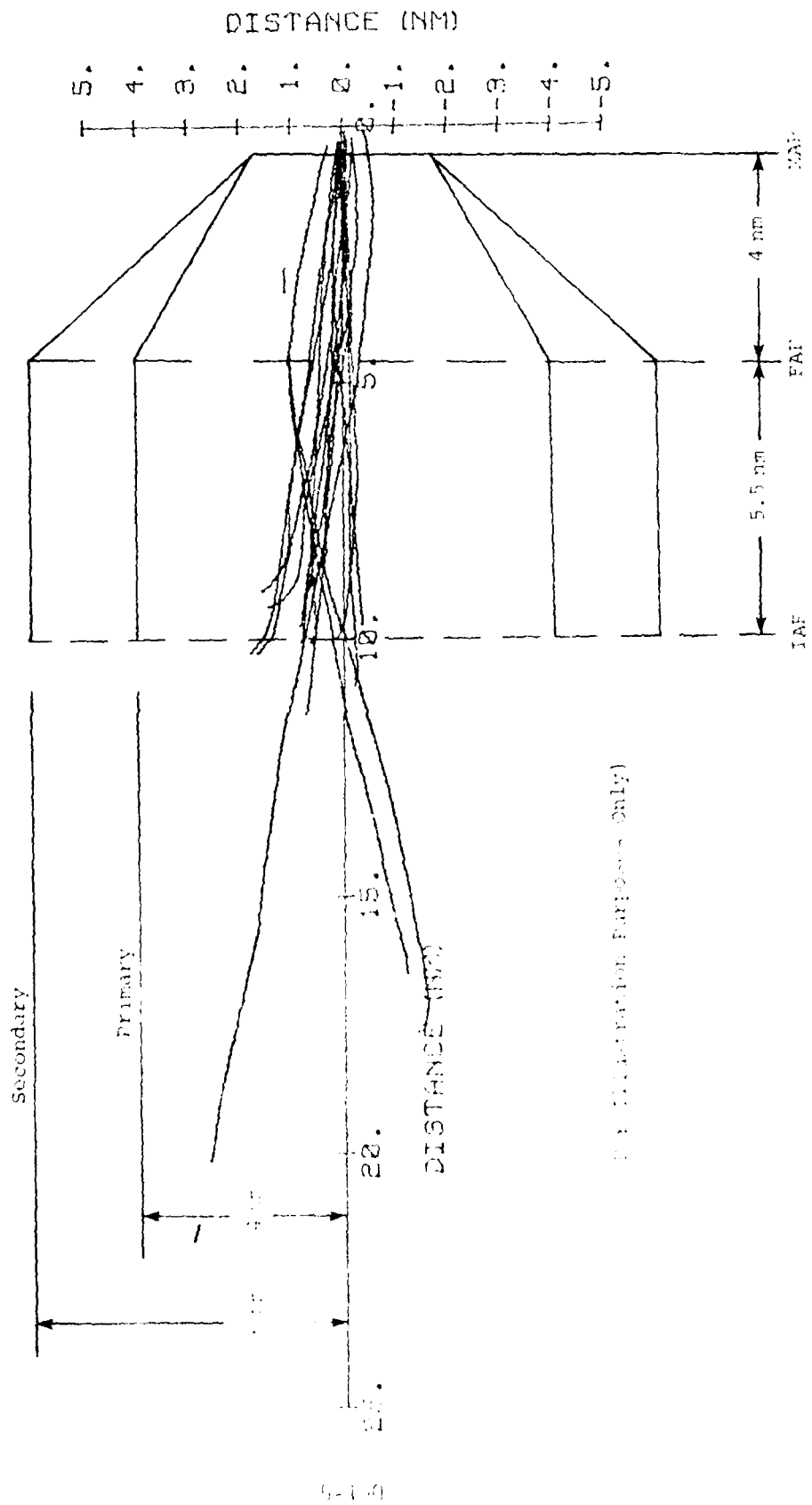
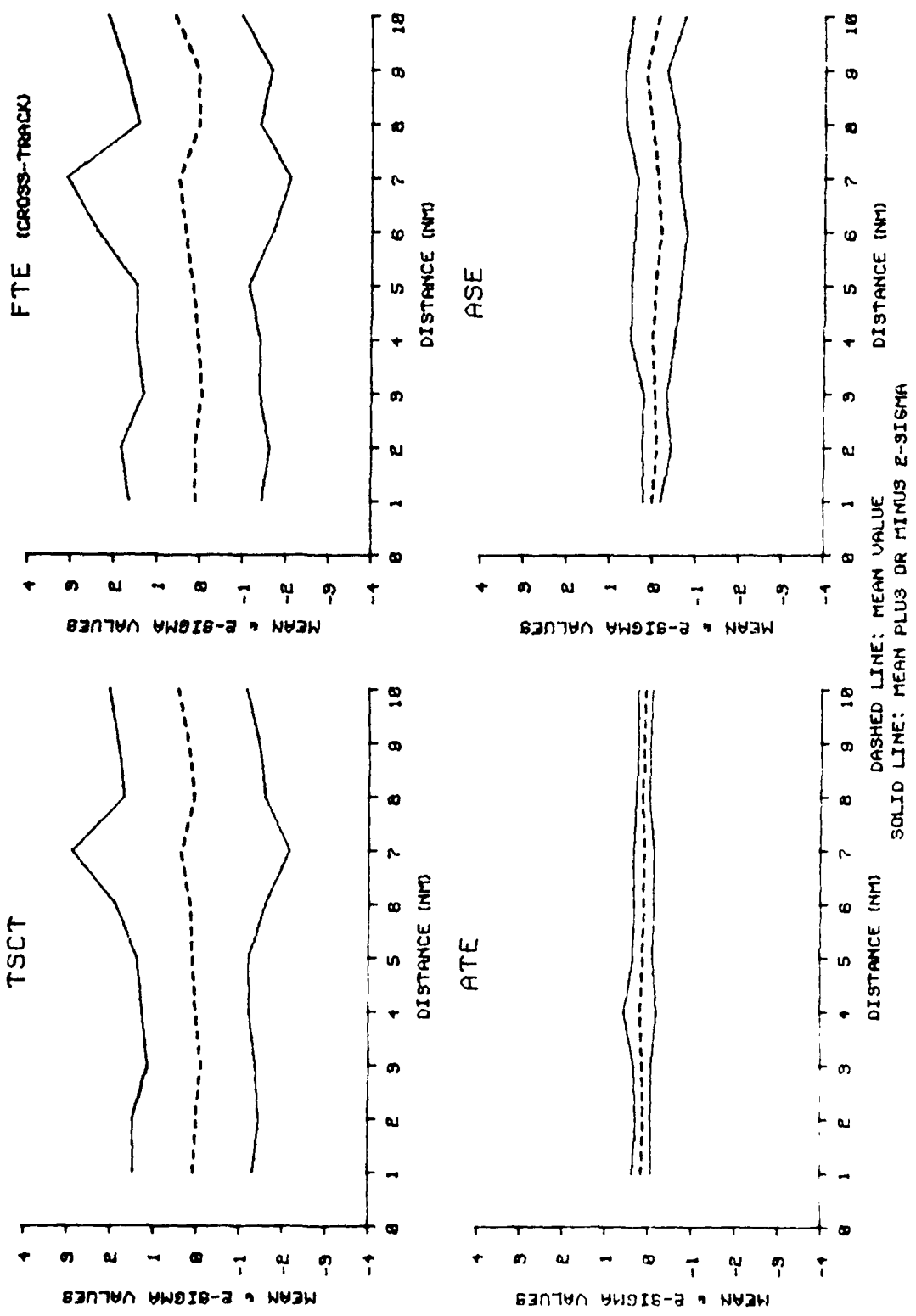


Figure 1.10 APA Airport Multiple Beacon Approaches Related To Obstacle Clearance Airspace

The approaches indicated in Figure 5.40 were also flown with great precision and all lie within airspace boundaries of ± 2.0 nm between the IAF and MAP. Reference 2, Terminal Instrument Procedures (TERPS) shows that for a standard NDB approach primary airspace requirements at the IAF are ± 3 nm. Figure 5.38 (single-beacon approaches) indicates that the approaches flown also lie inside of a ± 3 nm airspace region, in fact they lie within an airspace region that is ± 2 nm.

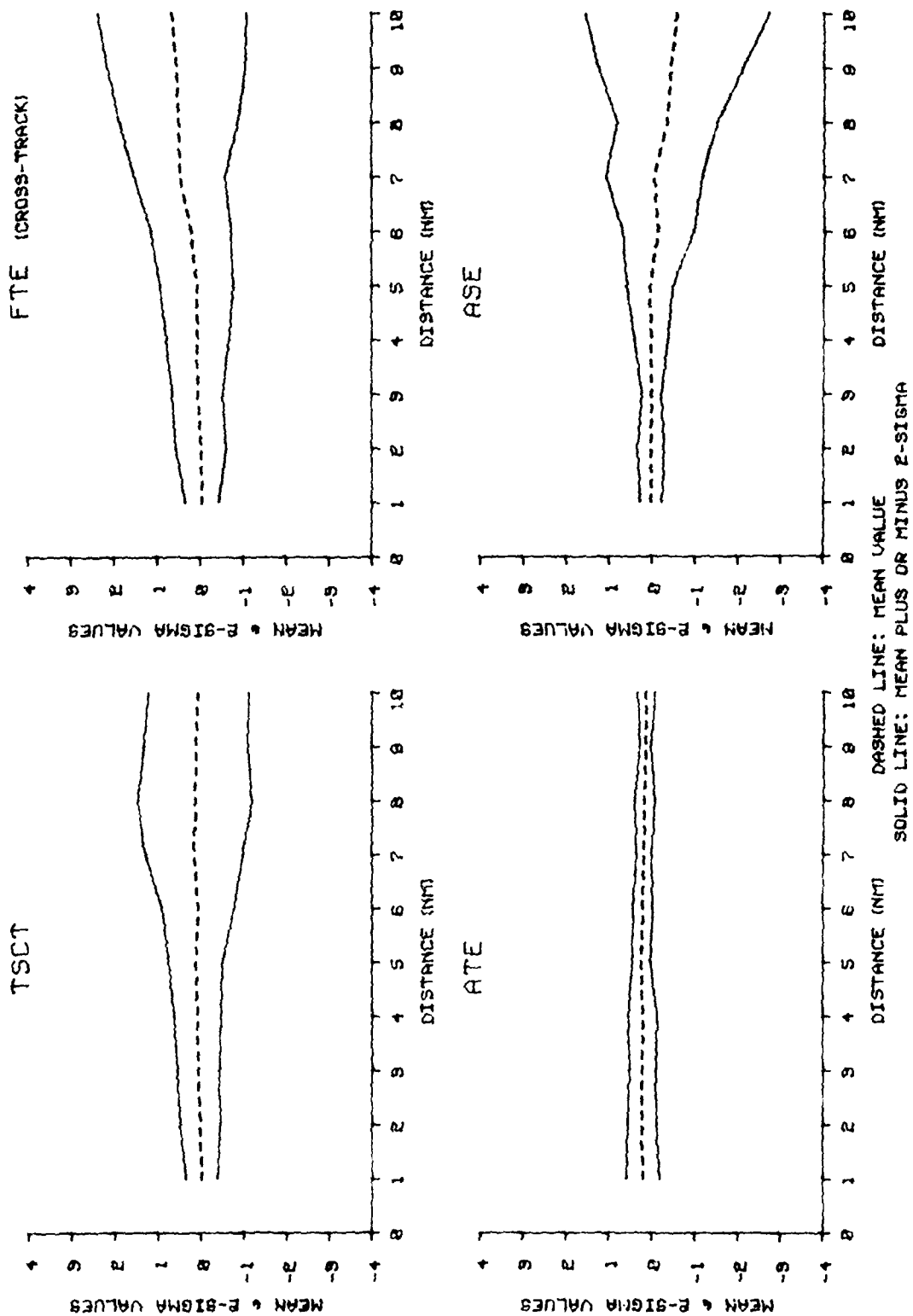
Figures 5.41 - 5.43 are graphical representations of Total System Cross Track Error (TSCT), Flight Technical Error (FTE), Airborne System Error (ASE), and Along Track Error (ATE). The mean value and mean ± 2 -sigma values are plotted vs. distance to the beacon starting at ten (10) miles. The significance of these figures is strictly with reference to airspace requirements. Figure 5.41 indicates that for the single beacon approaches the TSCT, FTE, ASE and ATE mean ± 2 -sigma values are virtually constant with range from the beacon, converging only slightly in the ASE case as the target is approached. It is surprising to note that the TSCT and FTE mean ± 2 -sigma values are constant when in fact they should converge as the target is approached. Figure 5.42 indicates that for the beacon with cursor approaches the TSCT, FTE and ASE mean ± 2 -sigma values converge as the target is approached, while the ATE values remain constant. The same facts are evident for the multiple beacon TSCT, FTE, ASE and ATE values indicated in Figure 5.43. Figure 5.43 does show that in the TSCT case the mean ± 2 -sigma error quantities stay virtually constant between eight (8) and three (3) nautical miles. The FTE and ASE quantities as mentioned earlier converge as the target is approached.

With the above facts in mind two conclusions can be drawn. First, the approaches flown utilizing the track orientation techniques require less airspace especially as the target is approached. Second, testing to date on Airborne Radar Approaches indicates they would work well in the non-precision approach environment. The procedures would necessitate little ATC structural change to integrate the ARA approaches at airport sites into the present system. But as mentioned earlier in Section 5.4.1, unless the approach is straight in, i.e., no holding patterns are required, etc., some other means of navigation is required to acquire the IAF. If two sets of procedures are required then complications set in that involve both the pilot and controller. ARA is a viable concept that with careful consideration can integrate with the present ATC system.



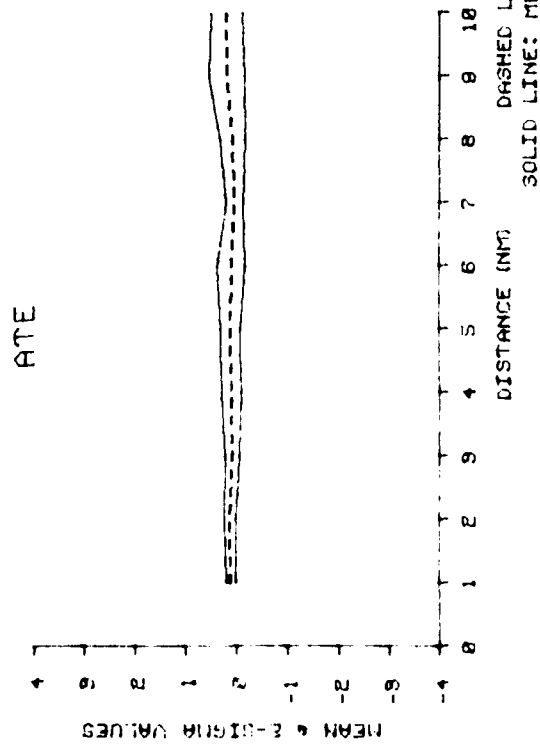
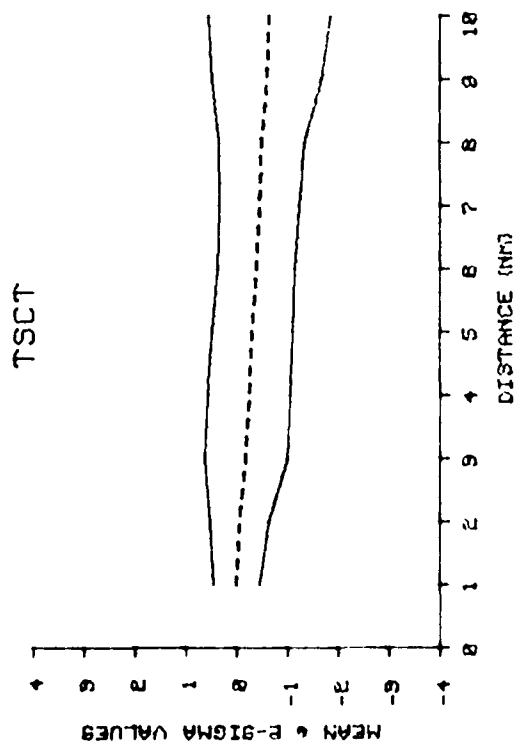
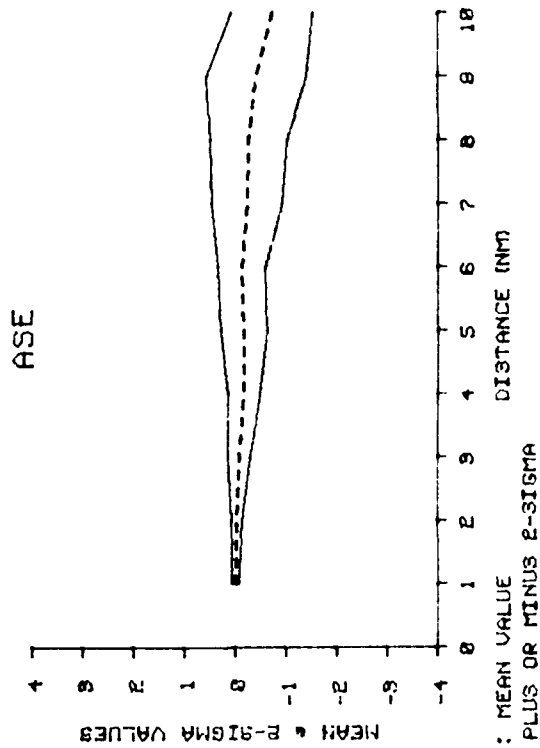
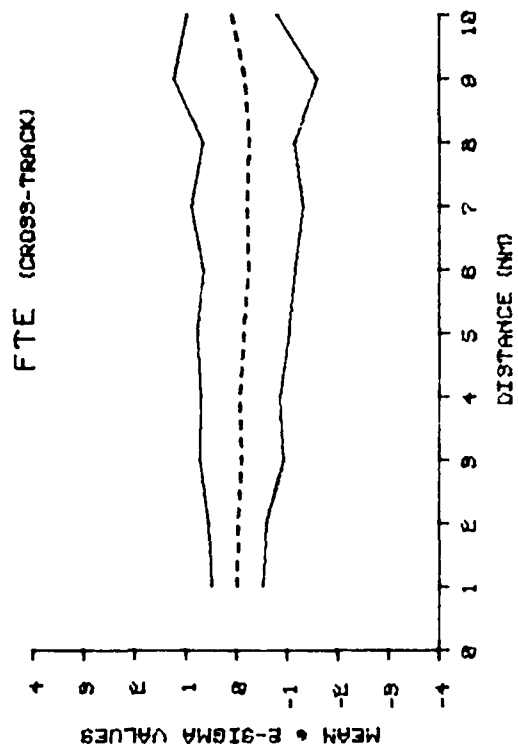
NOTE: Data Derived From 11 Approach Segments

Figure 5.41 Airport Site Single Beacon Mode: Mean, Mean Plus Or Minus 2-Sigma Values



NOTE: Data Derived From 17 Approach Segments

Figure 5.42 Bendix RDR-1400A Beacon With Cursor: Mean, Mean Plus Or Minus 2-Sigma Values



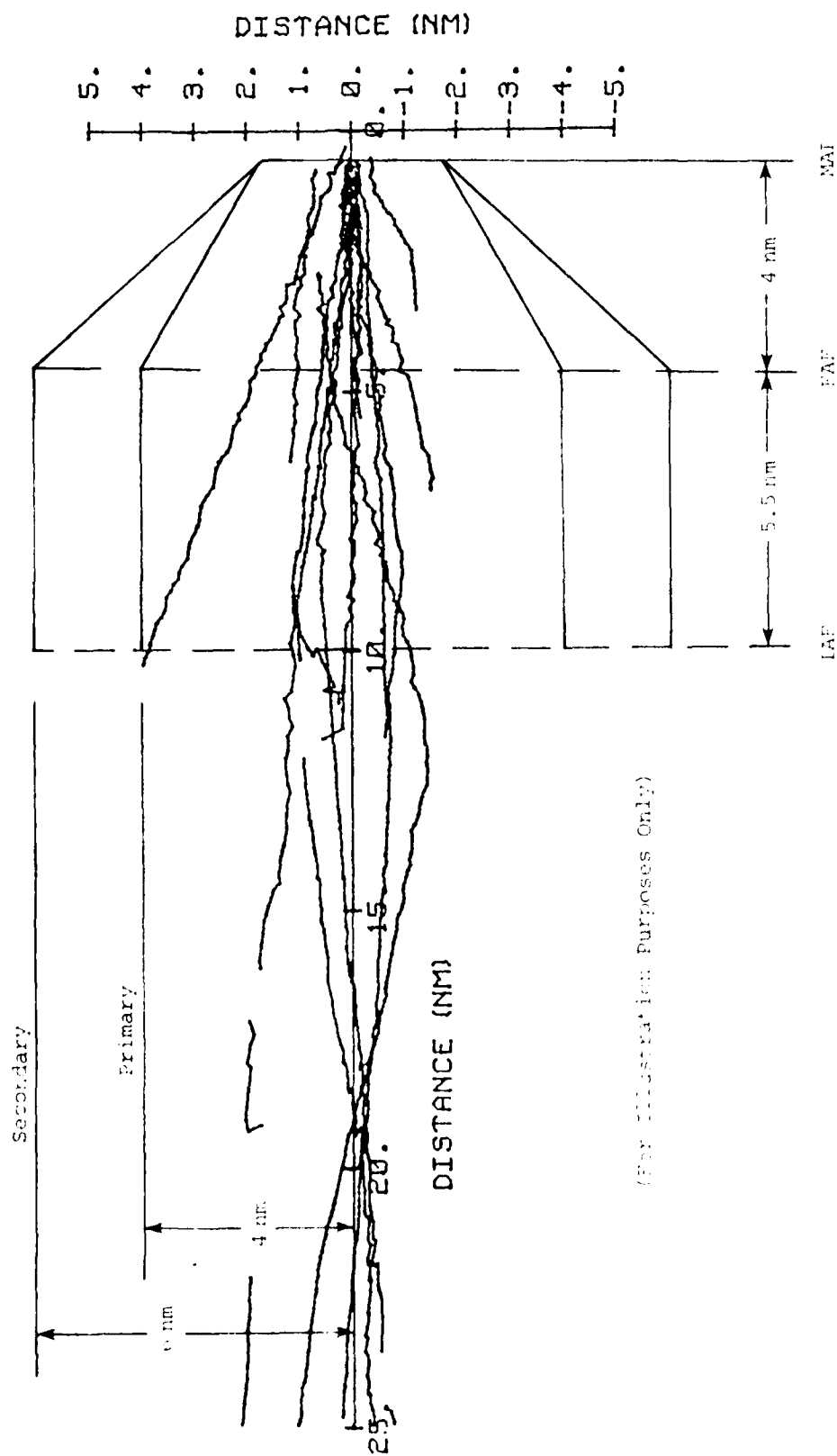
Y-axis values derived from 15 Approach Segments

Legend: Dashed line: Mean Value
Solid line: Mean Plus Or Minus 2-Sigma Values

5.4.2 Offshore ATC Procedures

Offshore ATC procedures utilized will be quite different from the landside procedures. These offshore targets typically consist of prominent surface objects such as oil rigs, lighthouses, and buoys, or beacons placed on these targets. Since the targets are so far offshore, conventional navigation aids are virtually non-existent with the exception of NDB's located on some oil rigs. The airborne radar system is a low cost, dependable answer to the situation.

The ATC procedures utilized would basically consider two items: first, obstruction clearance, which is very important to the operator who flies to a cluster of oil rigs and wants to execute an approach, and second, what weather minimums are necessary to safely conduct the approach in the presence of surrounding oil rigs, ships or lighthouses. Figures 5.44 - 5.48 present in graphical form the ARA offshore approaches as they relate to obstacle clearance. The test areas presented in Figures 5.44 - 5.48 are as follows: single beacon-only, skin paint, skin paint with cursor, Primus-50 combined mode and Primus-50 beacon-only mode, respectively. Figure 5.44 presents the airspace plot for the single beacon approach testing. The Figure illustrates that within ten (10) nautical miles all of the approaches lie inside a ± 2 nm region with the exception of two. Even these two approaches still lie inside the airspace requirements established by RTCA SC-133 as represented in Figure 5.44. Figure 5.45 presents the airspace requirements for the offshore skin paint tests. As indicated in Figure 5.45 all of the approaches that were flown to the correct target lie within a ± 1 nm region, but on two occasions the pilot flew to the wrong target taking the aircraft outside of the airspace boundaries. Figure 5.46 presents the airspace plot for the Skin Paint with Cursor Approach testing. Between the IAF and MAP all of the approaches flown lie inside of a ± 2 nm route wide, well within established RTCA SC-133 limits. Figures 5.47 and 5.48 presents the airspace plots for the RCA Primus-50 combined and beacon-only mode testing, respectively. All of the approaches flown during the Primus-50 test period lie within required airspace boundaries. All of the approaches flown during the offshore testing were within specified limits with the exception of a few skin paint approaches. This only verifies the fact that it is essential to have some means of positive target identification before the approach



(For Illustration Purposes Only)

Figure 5.44 ARJ Offshore Single Beacon Approaches Related To Obstacle Clearance Airspace

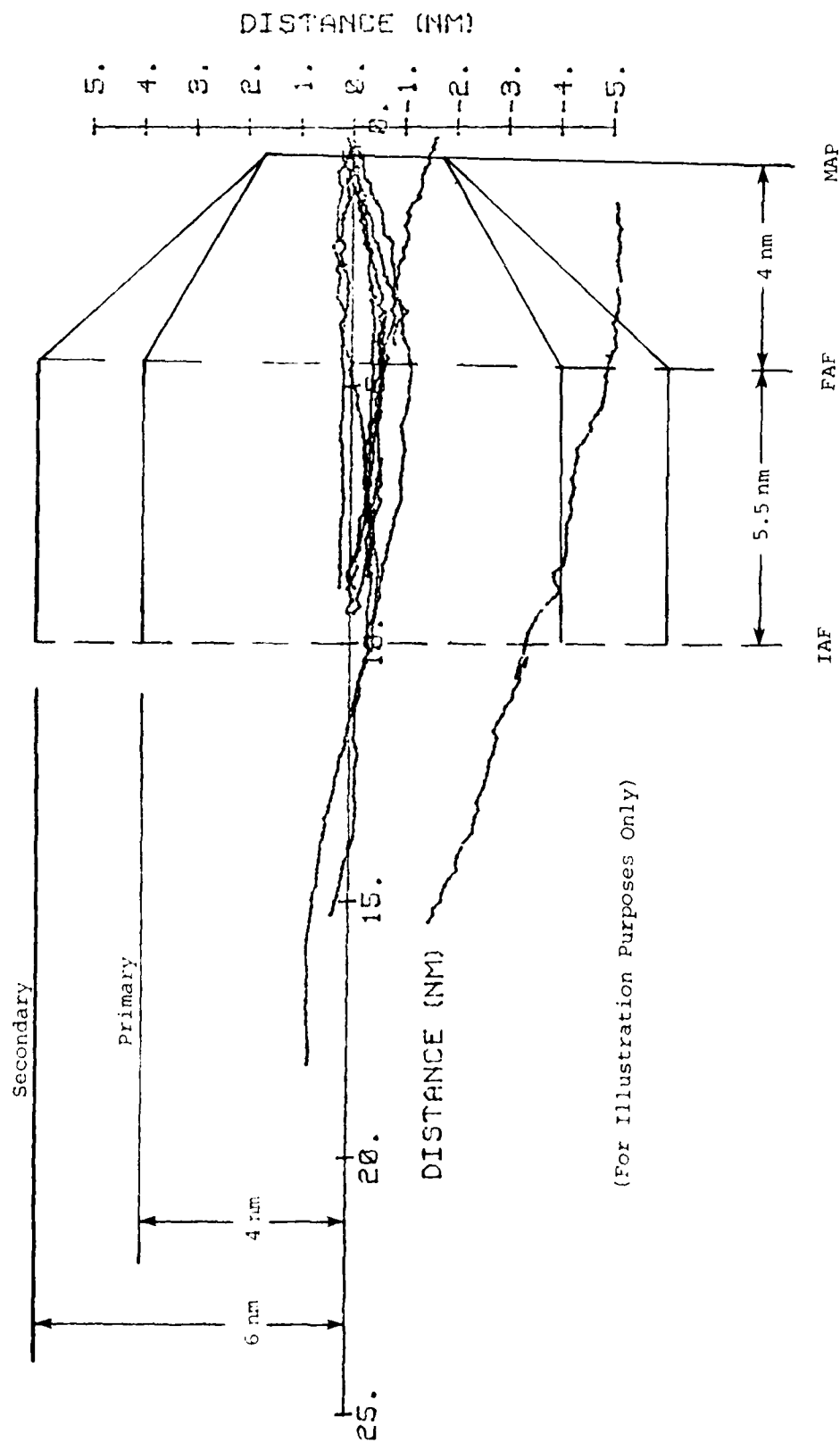
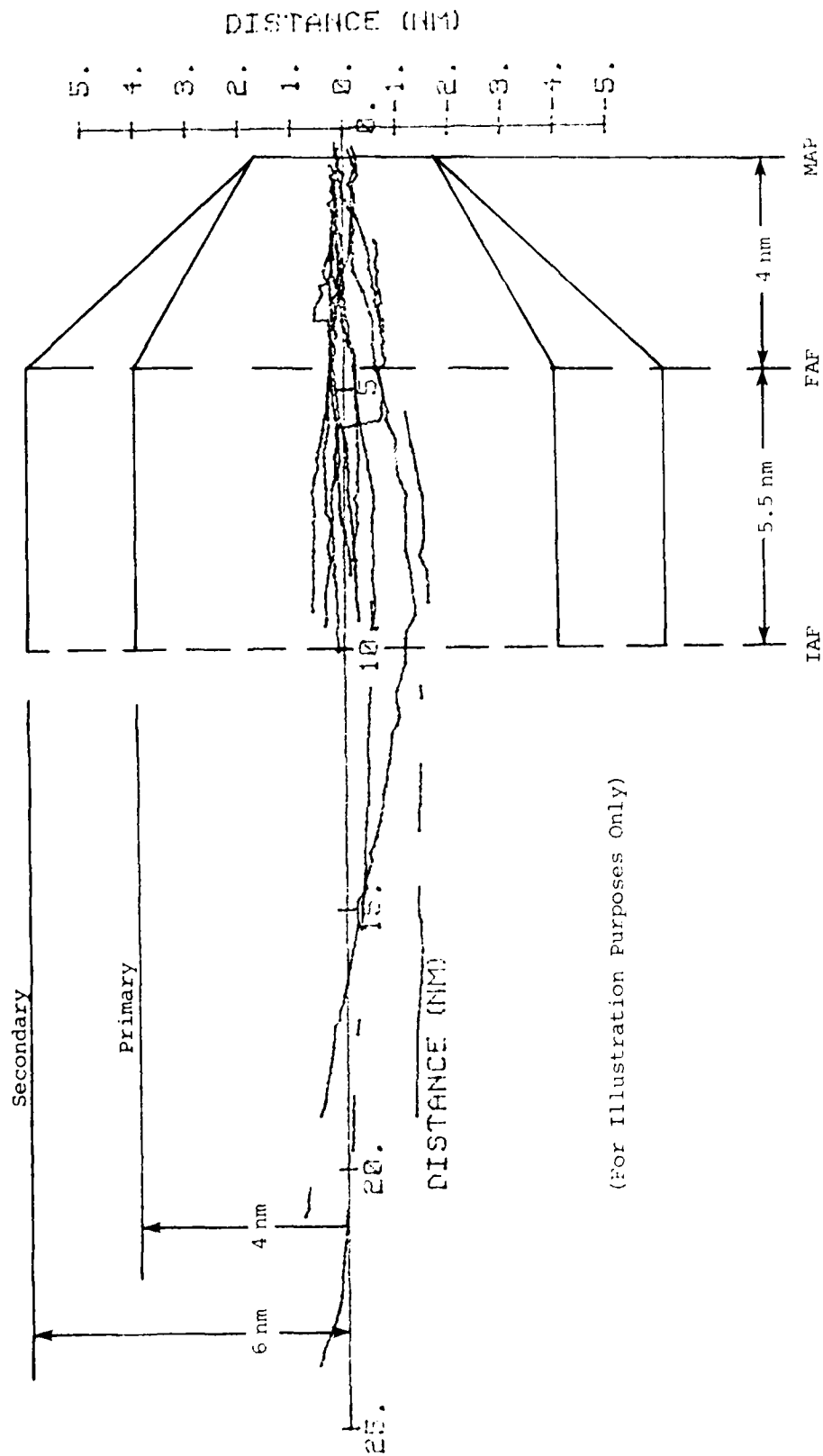
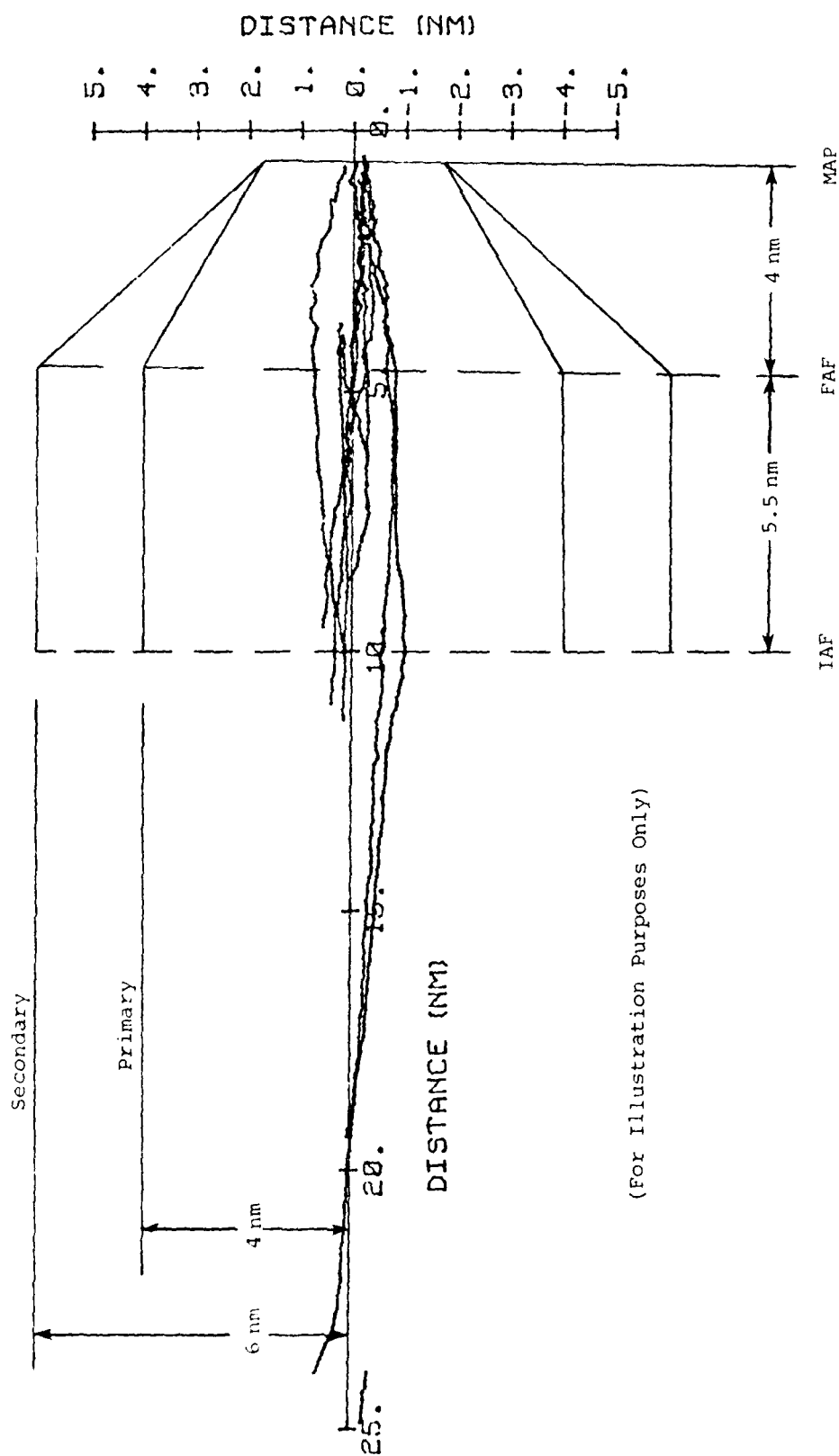


Figure 5.45 ARA Offshore Skin Paint Approaches Related To Obstacle Clearance Airspace



(For Illustration Purposes Only)

Figure 5.46 ARA Offshore Skin Paint With Cursor Approaches Related To Obstacle Clearance Airspace



(For Illustration Purposes Only)

Figure 5.47 ARA Offshore Primus-50 Combined Mode Approaches Related To Obstacle Clearance Airspace

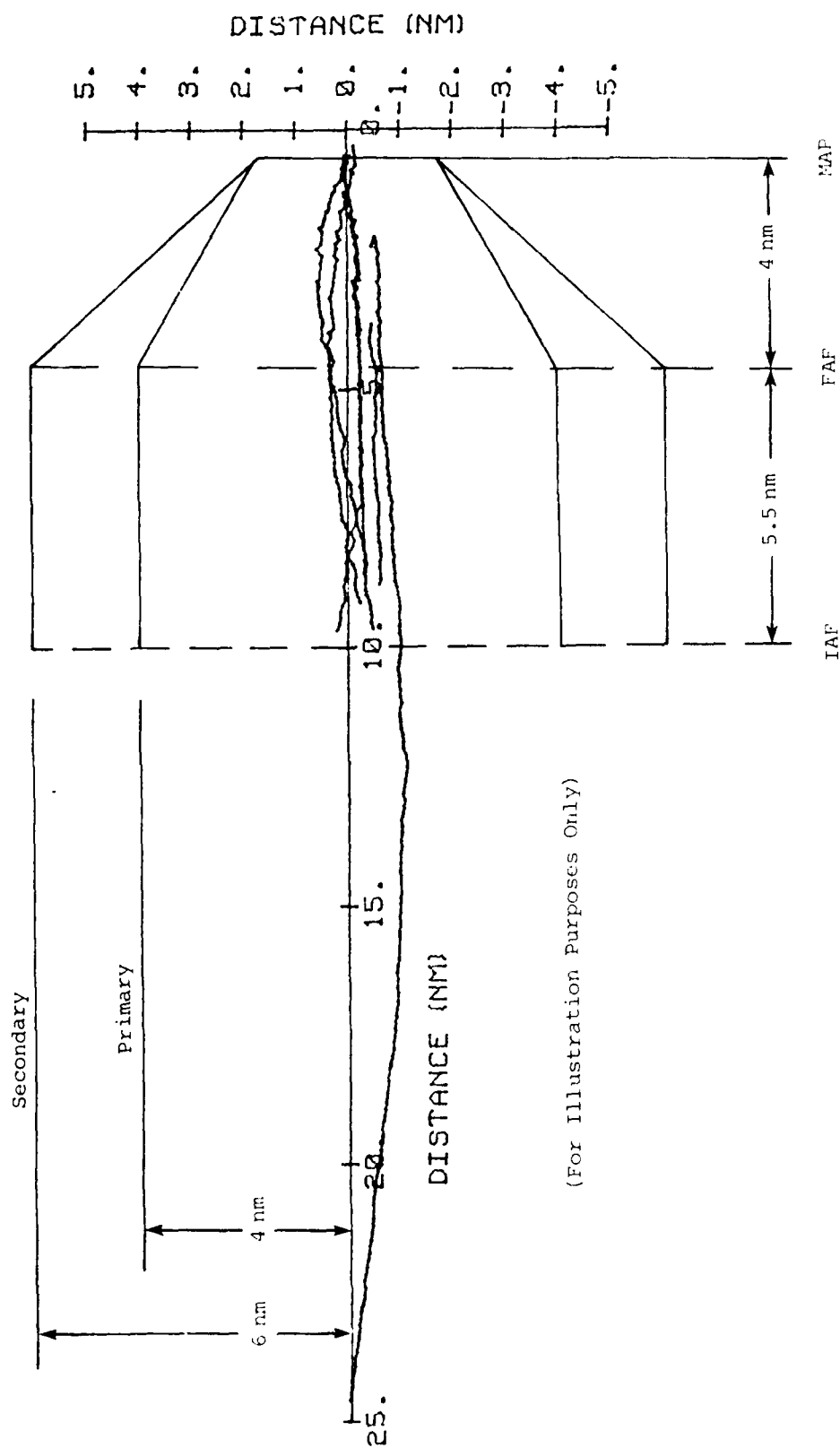
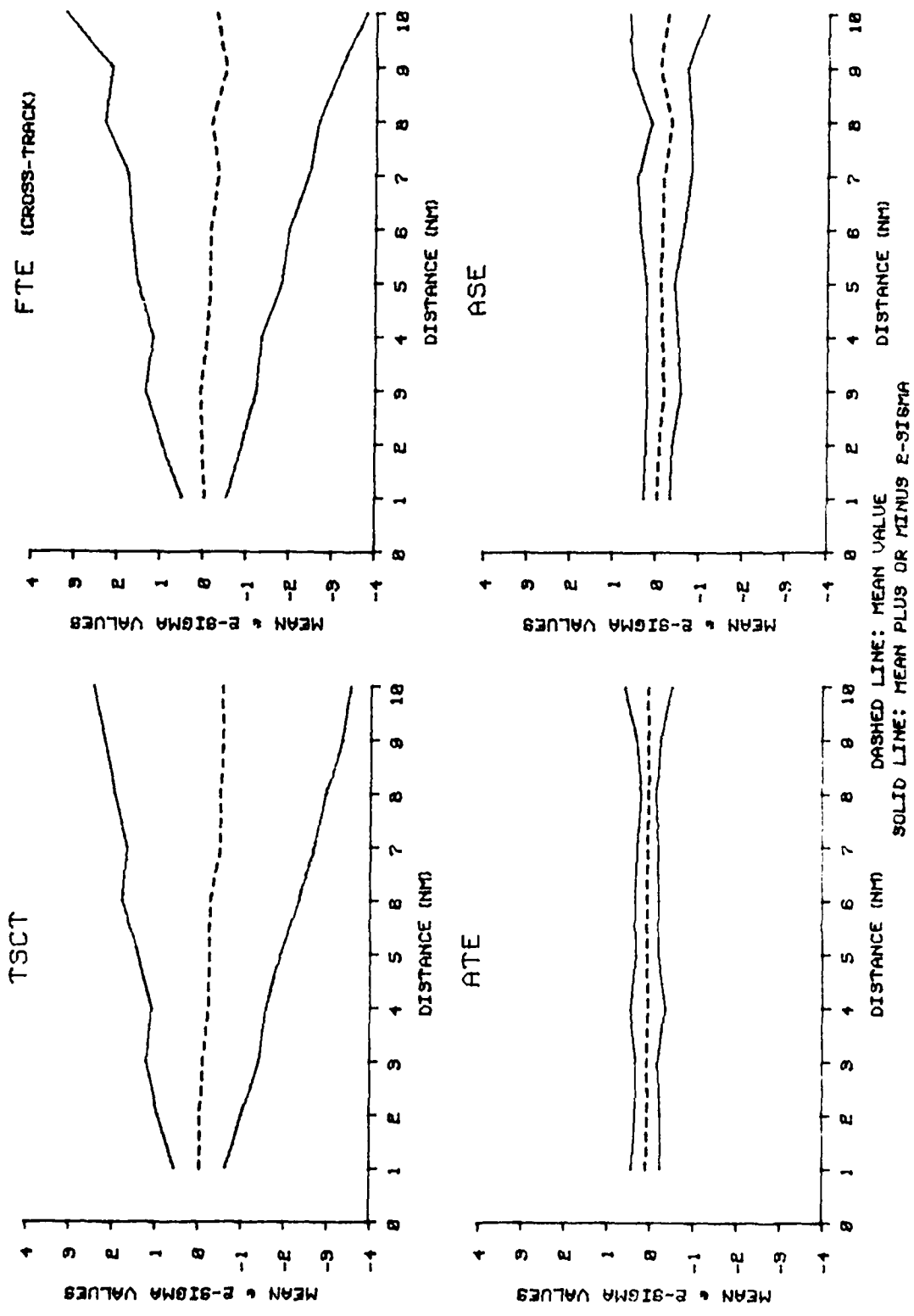


Figure 5.48 ARA Offshore Primus-50 Beacon-Only Approaches Related To Obstacle Clearance Airspace

can be conducted down to minimums safely. Figures 5.49 - 5.53 are graphical representations of the mean and mean ± 2 -sigma values vs. distance to the beacon for four specific error quantities. They are as follows: TSCT, FTE, ASE and ATE. Figure 5.49 indicates that the offshore single beacon mean ± 2 sigma values for the TSCT and FTE quantities converge as the beacon is approached, while the ATE and ASE mean ± 2 -sigma values are virtually independent of along track distance. Figure 5.50 shows some mean ± 2 -sigma results that are different than those seen in previous figures of this nature. Figure 5.50 indicates that the skin paint TSCT mean ± 2 -sigma values are virtually independent of range with some values converging at one (1) nautical mile and also converging at ten (10) nautical miles because of the lack of data points available. The FTE and ASE mean ± 2 -sigma values indicated in Figure 5.50 converge as the target is approached while the ATE values start to diverge at four (4) nautical miles from the target. Figure 5.51 presents the mean ± 2 -sigma results for the skin paint with cursor mode testing. The TSCT mean ± 2 -sigma values converge as the distance to the beacon decreases and the FTE values converge and diverge at varying distances from the target. The ATE values behave similarly to the FTE values while the ASE values in Figure 5.51 converge as the target is approached. Note, the values plotted in the skin paint mean, mean ± 2 -sigma plots do not include those approaches flown to the wrong target. Figures 5.52 and 5.53 presents the mean values and mean ± 2 -sigma values for the RCA Primus-50 test period. On both figures the TSCT and FTE mean ± 2 -sigma values behave similarly, that is, both sets of quantities remain virtually constant as the beacon is approached, converging only slightly close-in. Figure 5.52 shows that the combined mode mean ± 2 -sigma values for the ASE case converge as distance to the beacon decreases and the ATE quantities appear to be independent of range. Figure 5.53 shows that the beacon-only mode ASE and ATE mean ± 2 -sigma quantities are virtually independent of range with only a slight convergence in certain areas.

Table 5.28 presents the RCA Primus-50 beacon return area statistics. This table is presented to show the relative area covered on the radar screen by the RCA Primus-50 return. The quantities show that at the 75 nautical mile range setting a mean area of 20.25 nm² is covered by the beacon return. At the ten (10) nautical mile setting a mean area of 7.7 nm² is covered and at the two (2) nautical mile setting an area of .06 nm² is



NOTE: Data Derived From 12 Approach Segments

Figure 5.49 Bendix RDR-1400A Offshore Site Single Beacon Mode: Mean, Mean Plus Or Minus 2-Sigma Values

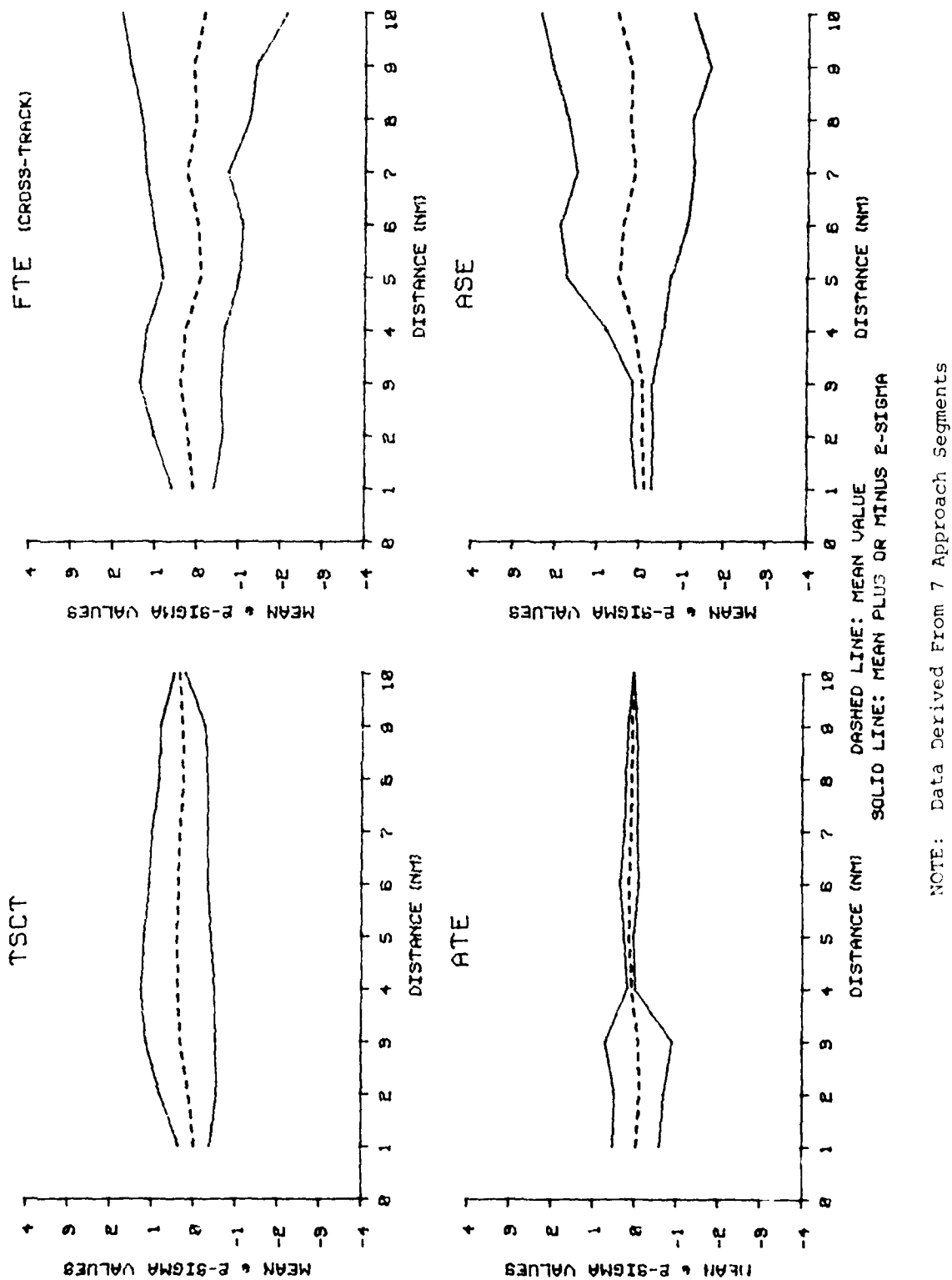
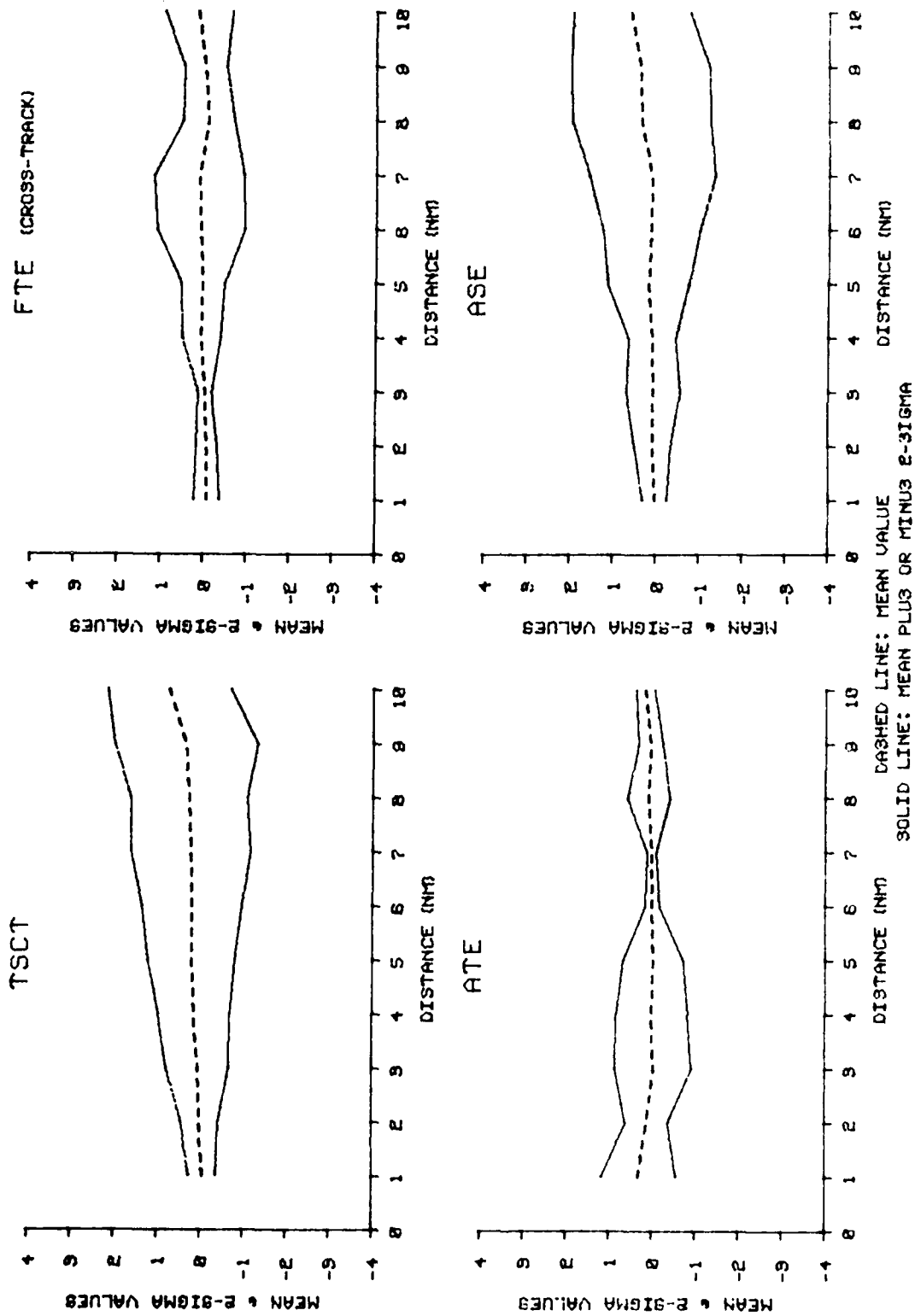
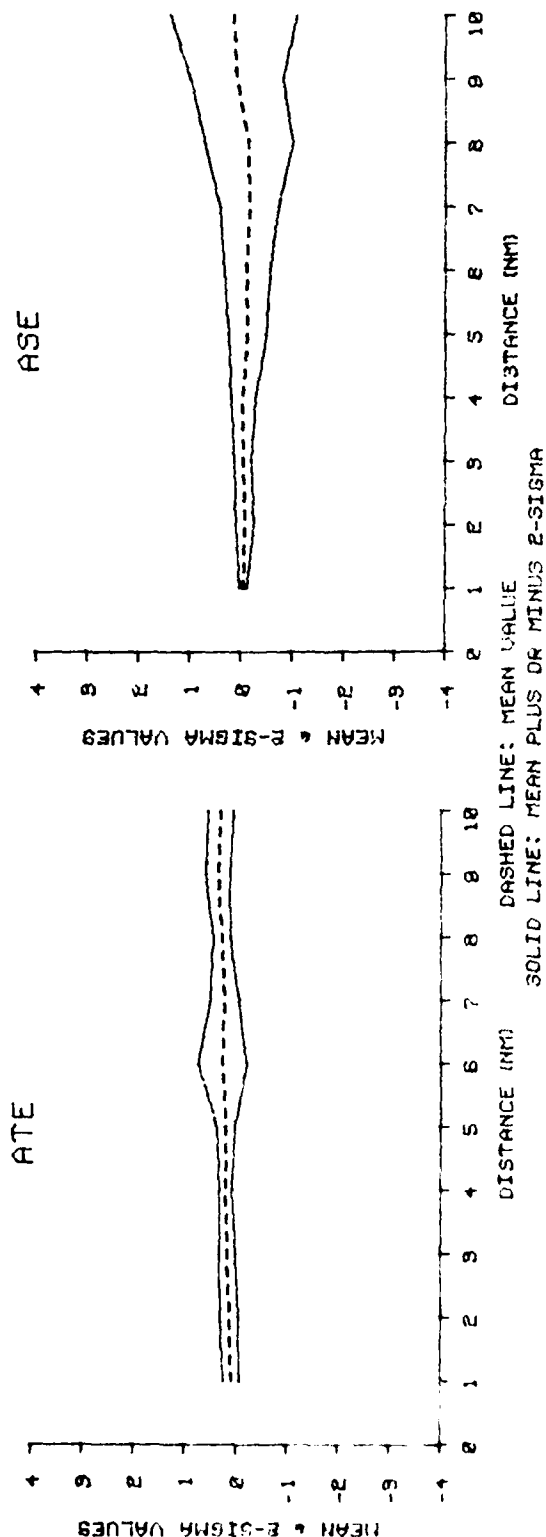
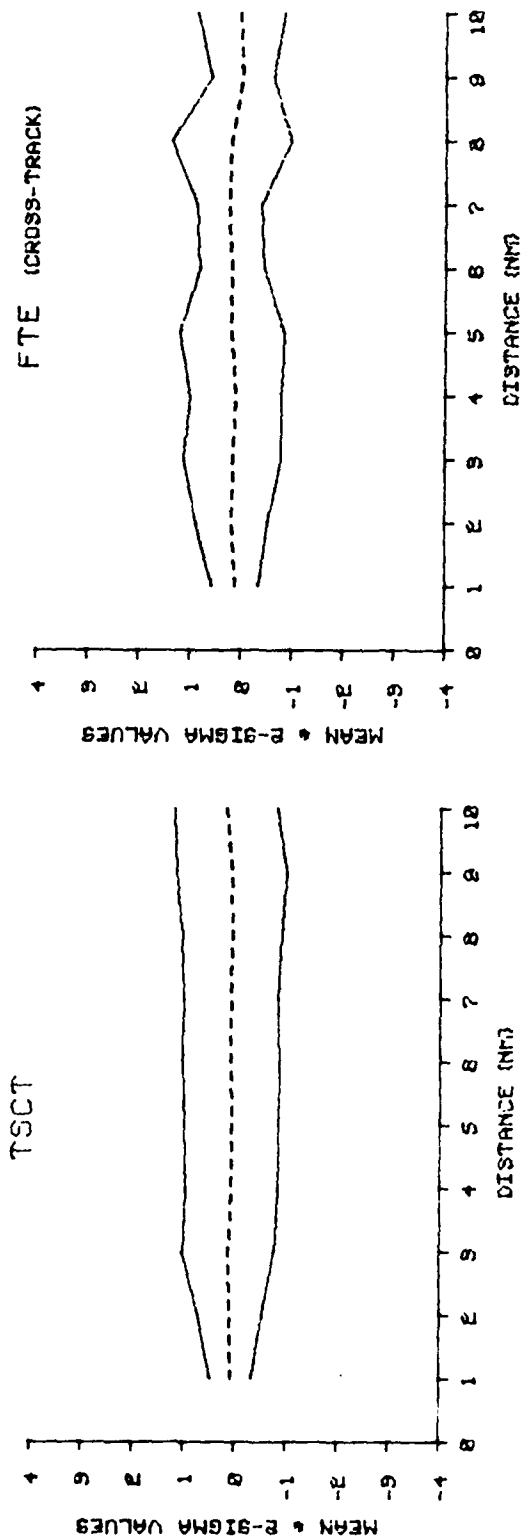


Figure 5.50 Bendix RDR-1400A Skin Paint Mode: Mean, Mean Plus Or Minus 2-Sigma Values



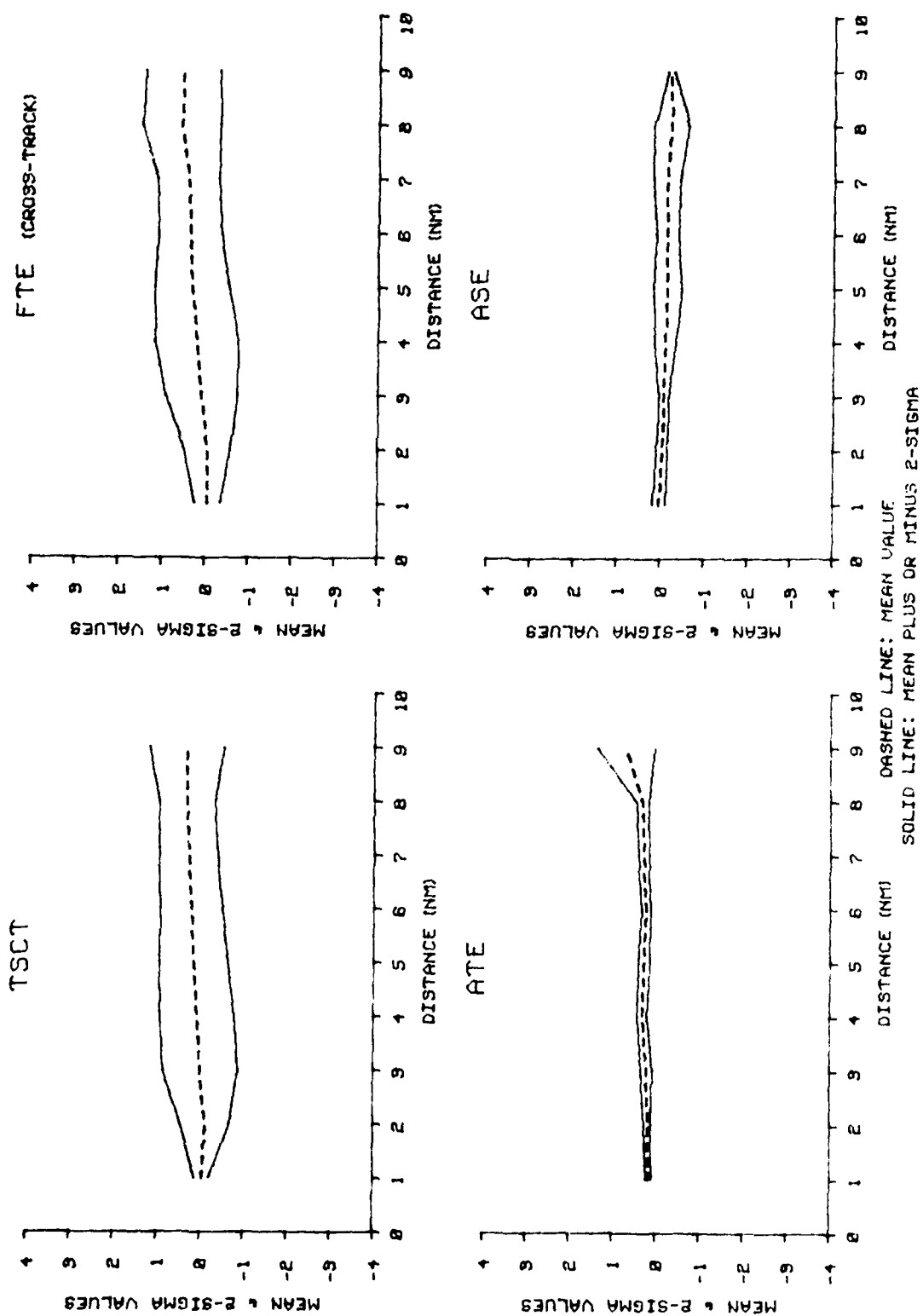
NOTE: Data Derived From 3 Approach Segments

Figure 5.51 Bendix RDR-1400A Skin Paint With Cursor: Mean, Mean Plus Or Minus 2-Sigma Values



NOTE: Data Derived From 2 Approach Segments

Figure 5.52 RCA Primus-50 Combined Mode: Mean, Mean Plus Or Minus 2-Sigma Values



NOTE: Data Derived From 6 Approach Segments

Figure 5.53 RCA Primus-50 Beacon-Only Mode: Mean, Mean Plus Or Minus 2-Sigma Values

blocked out by the Primus-50 return. These quantities are quite significant because in the combined mode, with the range selector set on 2.0 nm, skin paint targets within a 840 foot radius circle are not visible on the radar screen because of the large beacon return displayed. Since such a large area is covered by the return, obstacles close to the target are not displayed on the radar screen, therefore, offering no obstacle clearance information.

Table 5.28 RCA Primus-50 Beacon Return Area Statistics

Range Selector Setting	Mean (nm ²)	One-Sigma (nm ²)	Number Of Points
75	20.25	16.66	43
25	7.70	2.74	448
10	.43	.15	498
4	.14	.05	277
2	.06	.03	149

When flying to an offshore site the most critical stage of the approach is near the missed approach point. The missed approach procedures utilized will need to be executed in a direction that will direct the aircraft well clear of any obstacles. Since a cluster of oil rigs are usually situated so that 6-8 rigs lie very close to each other, operating in the skin paint mode might offer confusion to the pilot as to which oil rig to select for landing as shown by earlier examples. If operating in the beacon mode, a discrete return would be displayed at the landing site. This discrete target concept offers the pilot reassurance and establishes confidence during the final stages of the approach. For reliable missed approach procedures the pilot must be familiar with the formation of the cluster so he can choose the safest missed approach procedure according to his direction of flight. ARA for offshore use is very practical. It offers navigation where other navigational aids are unavailable and it offers the ability to display surface objects as well as discrete beacons.

6.0

SUMMARY OF ARA PERFORMANCE

This section summarizes the technical and operational performance of the Airborne Radar Approach (ARA) System. This summary includes the testing performed in the skin paint, skin paint with cursor, single beacon with cursor, multiple beacon, combined and beacon-only approach modes.

6.1 TECHNICAL PERFORMANCE

The technical performance objectives stated below are in response to the RTCA SC-133 "Minimum Operational Performance Standards" (MOPS) requirements. This is a summary of the quantitative data presented in detail in Section 5.3.

6.1.1 Range Performance

The beacon testing conducted utilizing various track orientation techniques showed basically the same range performance results obtained during the single beacon testing (Reference 1). That is, testing utilizing the Bendix Radar System showed a maximum acquisition range of 21 nm at an altitude of 1000 feet with the beacon at ground level. During the offshore RCA Primus-50 testing the beacon was situated approximately thirty feet from the water's surface, which allowed a consistent maximum acquisition of 35 nm at 1000 feet altitude. The minimum range at which the beacon could be tracked and displayed for both systems was .7 nm at 200 feet. These results were both qualitatively and quantitatively determined from the data collected during the track orientation techniques and RCA Primus-50 testing. No attempt was made during these tests to specifically determine the range performance during adverse weather conditions such as precipitation.

The offshore skin paint tests showed that since the lighthouse presented a target of such large radar cross section (approximately 100,000 m²) against a relatively low clutter background that it was almost always displayed at a range of 20 nm and an altitude of 1000 feet. However, the lighthouse target was virtually indistinguishable from the targets presented by nearby ships and was often unidentifiable until visual contact was established.

6.1.2 Bearing Accuracy

Table 6.1 presents the Airborne Radar Approach System bearing accuracy data for both the Bendix RDR-1400A and the RCA Primus-50 radar systems. The Bendix Airborne Radar Approach System was determined to have a mean accuracy in bearing with which a beacon return can be displayed of .56 degrees and a one-sigma of 3.1 degrees at five (5) nautical miles from the beacon. The bearing accuracy data presented in Table 6.1 for the Bendix ARA System in the skin paint mode showed a mean value of 3.7 degrees and a one-sigma of 5.4 degrees at the five (5) nautical mile point. The RCA Primus-50 radar system was determined to have a mean accuracy in bearing with which a beacon return can be displayed of -.15 degrees and a one-sigma value of 2.0 degrees at five (5) nautical miles. Data is also presented in Table 6.1 at ten nautical miles for the three above mentioned areas. SC-133 requires an accuracy of $\pm 3^\circ$ at all ranges.

Table 6.1 Airborne Radar Approach System Bearing Accuracy Data

Distance To Beacon	Bendix RDR-1400A Beacon Mode		Bendix RDR-1400A Skin Paint Mode		RCA Primus-50 Beacon & Combined Mode	
	\bar{x} (Deg)	$\pm 1\sigma$ (Deg)	\bar{x} (Deg)	$\pm 1\sigma$ (Deg)	\bar{x} (Deg)	$\pm 1\sigma$ (Deg)
5 nm	.56	3.1	3.7	5.4	-.15	2.0
10 nm	-3.3	6.1	3.3	3.8	.98	3.5

6.1.3 Display Readability

No specific tests were performed in this area. Qualitative observations showed that in direct sunlight the display was washed out, making it totally unreadable. In other forms of intense lighting the display readability was degraded but still could be resolved.

6.1.4 Display Resolution

Display resolution is inherently a system design characteristic, therefore, data obtained was to the same degree subjective in nature. As shown in Section 5.5 of Reference 1, a target width analysis of the Bendix Radar System showed a mean value of 13.2 degrees and a one-sigma

of 4.1 degrees. These values were obtained for all of the approaches flown during the single beacon testing. The RCA Primus-50 target area analysis showed at mean value of 7.7 nm^2 and a one-sigma of 2.74 nm^2 at the 25 nm range selector setting. At 2 nm range selector setting the target area analysis showed a mean value of $.06 \text{ nm}^2$ and a one-sigma of $.03 \text{ nm}^2$. It determined that even though the target displayed would have preferably been smaller, qualitatively it appears that the displayed size did not greatly affect the pilot's interpretation of the radar display for either system tested. It was, however, difficult for the pilot to identify laterally separated multiple beacons, while longitudinally separated multiple beacons could be distinguished at a 5000 foot spacing.

6.2 OPERATIONAL PERFORMANCE

This subsection will describe the operational performance of the ARA system using various track orientation techniques. The purpose of this subsection is to respond to the operational performance objectives stated in Section 3.0.

6.2.1 Beacon/Ground Clutter Discrimination

The combined beacon/ground mapping mode of operation offers two very important features; a) positive target identification, and b) obstacle clearance. The RCA Primus-50 was utilized for the combined mode testing phase. During the test period it was found that a major operational problem exists in the concept of the combined mode. The problem stems from the large beacon return that is displayed. The area covered by the return does not allow for any obstacle clearance within the immediate area of the intended target.

6.2.2 Offshore Target Discrimination

It was discovered during the offshore skin paint testing that while executing approaches to the lighthouse it was often times difficult to distinguish between ships and the lighthouse. On two occasions the wrong target was identified and tracked down to minimums. This lack of positive target identification could pose some very serious problems while executing an approach to an offshore site.

6.2.3 Cursor Interpretation

The use of an electronically generated cursor which obtains its input directly from HSI course selection proved very effective during the flight test program. Results showed that the cursor helped to decrease the Total System Cross Track (TSCT) and Flight Technical Error (FTE) quantities markedly. Results also indicated that the cursor aided approaches were conducted under conditions of decreased workload. The cursor technique provides the operator with orientation guidance relating to aircraft position and heading, desired course, and target location.

6.2.4 Performance In The Skin Paint And Skin Paint With Cursor Modes

The Bendix RDR-1400A radar system performed well in the skin paint and skin paint with cursor modes. As mentioned earlier the only serious problem encountered was that of positive target identification, which in turn creates a very high workload situation. The cursor aided approaches proved quite effective by reducing the overall TSCT and FTE values. The displayed target size was large, as was the case in previous testing, but the size did not present any operational problems.

6.2.5 Performance In The Single Beacon With Cursor Mode

Results in Section 5.3.3 indicated that the beacon with cursor tests proved very successful. The track orientation guidance provided by the generation of the cursor on the radar screen afforded the pilot a decreased workload situation and better track guidance. Plots presented in Section 5.3.3 show that the tendency to "home" to the station is eliminated with the use of the cursor. A comparison between the single beacon testing conducted earlier showed a large decrease in the TSCT and FTE quantities, while the ASE and ATE values continued to remain small. The ASE and ATE values reflect a system accuracy that is quite good, which also correlates to the qualitative assessment of the system.

6.2.6 Performance In The Multiple Beacon Mode

This mode of operation allowed the pilot to determine course error by creating a mental image of the track angle error utilizing two longitudinally separated beacons. Results indicate that this particular mode of operation does offer an increase in approach accuracy. Quantities indicated in Section 5.3.4 also show a decrease in the TSCT and FTE quantities over

those obtained during the airport single beacon testing. It was discovered though that because the course error is not directly displayed on the radar screen the mental workload involved in flying the approaches was greater. Gain control also caused a major problem during this portion of testing. Later after the completion of the tests it was discovered by the Bendix Corporation that the STC was improperly adjusted. This maladjustment caused serious display problems close-in to the target because proper gain adjustment for one beacon meant that the other beacon was either splayed across the entire screen or lost completely. Because there is no means for beacon identification on occasions when one beacon was inoperative, positive intended target identification was impossible.

6.2.7 RCA Primus-50 Combined And Beacon-Only Mode Performance

The RCA Primus-50 Radar System performed well in the combined and beacon-only modes. Results presented in 5.3.5 show that the TSCT and FTE values are reasonably small. Operationally the combined mode performed well. The test results indicated only one major operational problem, which stems from the size of the displayed beacon. In the combined mode the Primus-50 Radar System flashes the beacon return on and off at one second intervals. This allows the operator positive target identification, but due to the size of the displayed beacon skin paint targets in the immediate area are blocked out by the return. The pilots also indicated during this phase of testing that the large displayed beacon made navigation difficult at times, namely in determining the azimuth of the beacon relative to zero azimuth. The beacon-only results indicated the same orders of magnitudes as the combined mode results for all of the error quantities computed.

7.0

CONCLUSIONS

The major conclusions from the operational flight test evaluation of the Airborne Radar Approach (ARA) system using various track orientation techniques and operational modes are summarized in this section. These conclusions are, by intent, qualitative in nature. The quantitative results from which these conclusions were reached are summarized in Section 6.0 and discussed in depth in Section 5.0. These conclusions are organized to represent a qualitative summary of the detailed evaluation objectives presented in Section 3.0.

● Skin Paint Mode

- 1) The Airborne Radar Approach Systems's ability to distinguish offshore targets such as lighthouses from ships and other surrounding surface objects is quite limited.
- 2) Since there is no positive intended target identification capability, obstacle clearance can not be assured at approach minimums.

● Combined Mode

- 1) The combined mode offers the unique capability of providing obstacle clearance while at the same time offering positive target identification.
- 2) The combined mode does offer one serious problem. Due to the large size of the displayed beacon on the radar system tested, skin paint targets in the immediate area are blocked out.

● Cursor Interpretation

- 1) The cursor technique proved very effective in terms of track orientation in both the beacon and skin paint modes.
- 2) The cursor technique affords the pilot the ability to fly a predetermined inbound course instead of "homeing" to the station. This fact is evident from the large reduction in the TIL and FTL errors for the cursor aided approaches.

- 3) The cursor offers a very quick and easy course orientation reference, therefore reducing the level of mental workload involved in flying the approach.
- 4) The cursor technique is a very low cost solution to track guidance that can be easily implemented in the present "state-of-the-art" radar systems.

● Multiple Beacon Mode

- 1) The multiple beacon technique proved effective in track orientation while utilizing various longitudinal beacon spacings.
- 2) The multiple beacon techniques also showed a decrease in the TSCT and FTE error quantities over those quantities calculated in the single beacon mode.
- 3) Since the beacon targets are not uniquely identified when one of the ground based beacons becomes inoperative, positive identification of the intended target is rendered impossible.
- 4) More advanced Sensitivity Time Constant (STC) circuitry is required so that multiple beacons are displayed at equal sizes with one gain setting.
- 5) The mental workload involved in flying a multiple beacon approach is higher because the track angle error is not directly displayed on the radar screen.

● Beacon Mode vs. Skin Paint Mode Comparison

Operationally both modes of operation have their own specific problems. The Airborne Radar Approach System is an operationally viable navigation aid to landing. The skin paint mode offers the ability to identify obstacles that surround the landing site, but offers no positive identification of the site itself. The beacon mode on the other hand offers positive site identification, but no obstacle discrimination.

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● General Conclusions

- 1) The Airborne Radar Systems tested performed accurately at the airport and offshore sites in all of the various operational modes.
- 2) The Airborne Radar Approach System range performance is adequate at minimum ranges, but maximum range performance at 1000 feet altitude should be improved as regards the requirements of RTCA SC-133.
- 3) For both systems tested the Airborne Radar Approach System bearing accuracy proved to be very acceptable.
- 4) The display readability of the Airborne Radar Approach System is poor under high ambient light conditions.
- 5) While large target widths and target sizes were usually encountered, this did not affect the operational performance or display interpretability of the Airborne Radar Approach System.
- 6) Unidentified beacon returns caused some operational problems.
- 7) The airborne system cross track error was found to be quite good.
- 8) Data showed that without the use of some type of track orientation device the TSCT and FTE errors reflected the tendency to use ARA as a homing device rather than a cross track error "nulling" device.
- 9) The Airborne System along track error was very good, again confirming the quality of the airborne system itself.
- 10) The pilots utilized for the Airborne Radar Approach flight test performed very well. The workload involved in flying the approach necessitates two crew members, not one.

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